SUMMARY OF BOARD ITEM

ITEM # 02-1-4: **PUBLIC HEARING TO CONSIDER AMENDMENTS TO THE ALTERNATIVE FUEL REGULATIONS REGARDING COMPRESSED NATURAL GAS AND LIQUEFIED PETROLEUM GAS**

STAFF RECOMMENDATION: The staff recommends that the Board approve the proposed amendments to the Alternative Fuel Regulations regarding compressed natural gas (CNG) and liquefied petroleum gas (LPG). These amendments will add an alternative specification for CNG based on methane number (MN), and will provide an exemption from the LPG motor vehicle specifications for small local LPG delivery trucks which deliver and operate on the same LPG cargo fuel.

DISCUSSION: In 1992, the Board adopted the alternative fuel regulations in anticipation that the specifications would be used by engine manufacturers to design vehicles to meet the increasingly stringent low emission vehicle (LEV) standards. The regulations include specifications for certification fuels for certifying new vehicles and specifications for commercial fuels for in-use vehicles. The certification specifications provide engine manufacturers with fuel quality specifications to design and certify engines. The commercial specifications (which are the sole subject of the proposed amendments) define the fuel that is used by motor vehicles operated in California. The commercial specifications ensure that in-use fuels are similar to the fuels used to certify new vehicles and engines, and to ensure the fuel quality in the market place to protect engines and maintain the emissions benefits of alternative fuels.

In the natural gas market, there are two specifications: one is the specification for motor vehicle fuel and the other is for residential/commercial use. However, there is only one infrastructure to deliver the fuels. In addition, there are areas in the State where the availability of natural gas meeting the motor vehicle fuel specifications is limited. Therefore, staff is proposing amendments to the alternative fuels regulations for CNG to increase compliance flexibility.

For CNG, the proposed amendments include an alternative statewide CNG methane number (MN) specification of at least 80. There is also proposed a limited alternative CNG specification of MN 73 for fleet operations in the Southern San Joaquin Valley (SSJV) and the South Central Coast (SCC) that meet the following criteria: 1) The fueling station cannot economically provide CNG meeting a MN of 80; 2) The fleet vehicles are capable to operate on CNG with a MN of 73 as recommended by the engine manufacturer; and 3) The fueling station has controls in place to prevent misfueling. Other amendments include definitions of the SSJV and the SCC.

Similar to CNG, there is also a commercial and motor vehicle fuel specification for LPG and only one infrastructure to deliver these fuels. Because certain delivery trucks operate on the fuel that is delivered, these trucks may be in violation of the regulation when the fuel does not meet the LPG motor vehicle specifications.

For LPG, the proposed amendments include an exemption for LPG delivery vehicles that deliver and operate on the same LPG cargo fuel. These vehicles would be allowed to operate on commercial grade or motor vehicle grade LPG.

In developing the proposed amendments, ARB staff conducted five CNG and three LPG public meetings from June 2000 to June 2001, and held numerous meetings with industry associations, environmental groups and other government agencies.

SUMMARY AND IMPACTS: In summary, the proposed amendments for CNG provide an alternative set of specifications in addition to the existing CNG specifications to add flexibility in the availability of complying motor vehicle CNG in California. The proposed amendments for LPG do not change the current LPG fuel specifications but provide an exemption from the fuel specifications for specific delivery vehicles thus making it more practical for LPG suppliers and distributors to market and sell their fuel. The proposed amendments are not expected to result in any adverse impact to either the public health or the environment.

TITLE 13. CALIFORNIA AIR RESOURCES BOARD

NOTICE OF PUBLIC HEARING TO CONSIDER AMENDMENTS TO THE CALIFORNIA ALTERNATIVE FUELS FOR MOTOR VEHICLE REGULATIONS

The Air Resources Board (the "Board" or "ARB") will conduct a public hearing at the time and place noted below to consider adoption of amendments to the compressed natural gas and liquefied petroleum gas specifications within the alternative fuels regulations. This proposal includes amendments to the definition and prohibition sections of the regulations.

DATE: February 21, 2002

TIME: 9:00 a.m.

PLACE: California Environmental Protection Agency
Coastal Valley Hearing Room, 2nd Floor
1001 "I" Street
Sacramento, CA 95814

This item will be considered at a two-day meeting of the ARB, which will commence at 9:00 a.m., February 21, 2002, and may continue at 8:30 a.m., February 22, 2002. This item may not be considered until February 22, 2002. Please consult the agenda for the meeting, which will be available at least 10 days before February 21, 2002, to determine the day on which this item will be considered.

This facility is accessible to persons with disabilities. If accommodation is needed, please contact the ARB's Clerk of the Board by February 7, 2002, at (916) 322-5594, or Telephone Device for the Deaf (TDD) (916) 324-9531 or (800) 700-8326 for TDD calls from outside the Sacramento area, to ensure accommodation.

INFORMATIVE DIGEST OF PROPOSED ACTION AND POLICY STATEMENT OVERVIEW

Sections Affected: California Code of Regulations (CCR), Title 13, Division 3, Air Resources Board, Chapter 5. Standards for Motor Vehicle Fuels, article 3. Specifications for Alternative Motor Vehicle Fuels, sections 2290, 2291, 2292.5, and 2292.6.

A. Background

The ARB alternative fuels regulations, adopted in 1992, include specifications for seven alternative fuels that are shown below:

- M-100 (100 volume percent methanol)
- M-85 (Nominally 85 volume percent methanol and 15 volume percent unleaded gasoline)
- E-100 (100 volume percent ethanol)
- E-85 (Nominally 85 volume percent ethanol and 15 volume percent unleaded gasoline)
- CNG (Compressed Natural Gas)
- LPG (Liquefied Petroleum Gas)
- Hydrogen

The regulations include specifications for certification fuels for certifying new vehicles and specifications for commercial fuels for in-use vehicles. The specifications were developed in anticipation that alternative fuels would be used by engine manufacturers to design vehicles to meet the increasingly stringent low emission vehicle (LEV) standards. The certification specifications provide engine manufacturers with fuel quality specifications to design and certify engines. The commercial specifications (which are the sole subject of the proposed amendments) define the fuel that is used by motor vehicles operated in California. The commercial specifications ensure that in-use fuels are similar to the fuels used to certify new vehicles and engines, and to ensure the fuel quality in the marketplace to protect engines and maintain the emissions benefit of alternative fuels. The following discusses the commercial CNG and LPG motor vehicle specifications.

Compressed Natural Gas

The motor vehicle specifications for CNG were developed in consultation with the natural gas industry, the automobile industry, the engine manufacturers, and other interested parties. The specifications developed were based on a consensus of the quality of natural gas that was imported and produced in California. The motor vehicle CNG specifications are contained in the California Code of Regulations (CCR), title 13, section 2292.5. The CNG specifications have not been amended since the original adoption.

Liquefied Petroleum Gas

The motor vehicle specifications for LPG were adopted in consultation with the LPG industry, automobile industry, the engine manufacturers, and other interested parties. The specifications were originally developed to be consistent with the Gas Producers Association (GPA) Standard 2140 and the American Society of Testing and Materials (ASTM) Designation D1835-89. However, the

Board later revised the specifications to be more representative of the quality of LPG that is produced and used in California. The LPG motor vehicle specifications are contained in CCR, title 13, section 2292.6.

Other CNG and LPG Motor Vehicle Fuel Specifications

There are no other legally enforceable specifications for CNG and LPG motor vehicle fuels in the United States. The Board's specifications for CNG and LPG for use in motor vehicles are the only required specifications for motor vehicle CNG and LPG, respectively. The United States Environmental Protection Agency does not have any specifications for motor vehicle CNG and LPG.

B. Proposed Amendments

The ARB staff is proposing the adoption of alternative CNG motor vehicle fuel specifications and an exemption for LPG bobtail trucks.

CNG

Staff is proposing to establish new CNG specifications based on methane number (MN) to provide more flexibility for producers and suppliers of CNG to comply with the specifications. These specifications will be an additional compliance option to the existing specifications. Specifically, staff proposes two additional specifications: a statewide specification of MN 80, and an alternative specification of MN 73 available in the Southern San Joaquin Valley (SSJV) and South Central Coast (SCC) to fleet operations that meet the following criteria:

- The fueling station cannot economically provide CNG meeting a MN of 80;
- The fleet vehicles can operate on CNG with a MN of 73 as recommended by the engine manufacturer;
- The fueling station has controls in place that will prevent misfueling.

Staff also proposes two definitions that are necessary to define the SSJV and SCC. For the purpose of these specifications, SSJV will be defined as inclusion of the following counties within the jurisdiction of the San Joaquin Valley Air Pollution Control District: Fresno, Kings, Tulare, and Kern counties. The SCC includes San Luis Obispo and Santa Barbara counties.

LPG

Staff is proposing to add a provision allowing small local delivery trucks, which deliver LPG fuel to non-motor vehicle accounts an exemption from the LPG motor vehicle specifications. Small local delivery trucks or "bobtails" are defined as a truck capable of being fueled off of the cargo tank with a maximum capacity of 3000 gallons. These vehicles would be allowed to operate on LPG that does not meet the motor vehicle fuel specifications.

AVAILABILITY OF DOCUMENTS AND AGENCY CONTACT PERSONS

The Board staff has prepared a Staff Report: Initial Statement of Reasons (ISOR) for the Proposed Regulatory Action, which includes a summary of the environmental impacts of the proposal. The Report is entitled, "Proposed Amendments to the California Alternative Fuels for Motor Vehicle Regulations."

Copies of the Staff Report and the full text of the proposed regulatory language, in underline and strikeout format to allow for comparison with the existing regulations, may be accessed on the ARB's web site listed below, or may be obtained from the Public Information Office, Air Resources Board, 1001 I Street, Environmental Resources Center, 1st Floor, Sacramento, CA 95814, (916) 322-2990 at least 45 days prior to the scheduled hearing (February 21, 2002). Upon its completion, the Final Statement of Reasons (FSOR) will be available and copies may be requested from the agency contact persons in this notice, or may be accessed on the ARB's web site listed below.

Further inquiries concerning the substance of the proposed regulation may be directed to the designated agency contact persons, Ms. Lesley E. Crowell, Air Resources Engineer, Industrial Section, (916) 323-7227, or Mr. Gary M. Yee, Manager, Industrial Section, at (916) 327-5986.

Further, the agency representative and designated back-up contact persons to whom nonsubstantive inquiries concerning the proposed administrative action may be directed are Artavia Edwards, Manager, Board Administration & Regulatory Coordination Unit, (916) 322-6070, or Marie Kavan, Regulations Coordinator, (916) 322-6533. The Board has compiled a record for this rulemaking action, which includes all the information upon which the proposal is based. This material is available for inspection upon request to the contact persons.

If you are a person with a disability and desire to obtain this document in an alternative format, please contact the Air Resources Board ADA Coordinator at (916) 323-4916, or TDD (916) 324-9531, or (800) 700-8326 for TDD calls outside the Sacramento area.

This notice, the ISOR and all subsequent regulatory documents, including the FSOR, when completed, are available on the ARB Internet site for this rulemaking at www.arb.ca.gov/regact/cng-lpg/cng-lpg.htm

COSTS TO PUBLIC AGENCIES AND TO BUSINESSES AND PERSONS AFFECTED

The determinations of the Board's Executive Officer concerning the costs or savings necessarily incurred in reasonable compliance with the proposed regulations are presented below.

The Executive Officer has determined that the proposed regulatory action will not create costs or savings, as defined in Government Code section 11346.5(a)(6), to any state agency or in federal funding to the state, costs or mandate to any local agency or school district whether or not reimbursable by the state pursuant to Part 7 (commencing with section 17500), Division 4, Title 2 of the Government Code, or other non-discretionary savings to local agencies.

In developing this regulatory proposal, the ARB staff evaluated the potential economic impacts on representative private persons or businesses. The ARB is not aware of any cost impacts that a representative private person or business would necessarily incur in reasonable compliance with the proposed action. Representative private persons will not be affected by cost impacts for this proposed regulation.

The Executive Officer has made an initial determination that the proposed regulatory action will not have a significant statewide adverse economic impact directly affecting businesses, including the ability of California businesses to compete with businesses in other states, or on representative private persons.

In accordance with Government Code section 11346.3, the Executive Officer has determined that the proposed regulatory action will not affect the creation or elimination of jobs within the State of California, the creation of new businesses or elimination of existing businesses within the State of California, or the expansion of businesses currently doing business within the State of California. A detailed assessment of the economic impacts of the proposed regulatory action can be found in the Staff Report (ISOR).

The Executive Officer has also determined, pursuant to Government Code section 11346.5(a)(3)(B), that the proposed regulatory action will not affect small businesses because this is a change to a regulation that is voluntary with respect to small businesses and there are no mandated requirements and no associated impacts.

Before taking final action on the proposed regulatory action, the Board must determine that no alternative considered by the agency or that has otherwise been identified and brought to the attention of the agency would be more effective in carrying out the purpose for which the action is proposed or would be as effective and less burdensome to affected private persons than the proposed action.

SUBMITTAL OF COMMENTS

The public may present comments relating to this matter orally or in writing at the hearing, and in writing or by e-mail before the hearing. To be considered by the Board, written submissions not physically submitted at the hearing must be received **no later than 12:00 noon, February 20, 2001**, and addressed to the following:

Postal mail is to be sent to:

Clerk of the Board
Air Resources Board
1001 "I" Street, 23rd Floor
Sacramento, California 95814

Electronic mail is to be sent to: cng-lpg@listserve.arb.ca.gov and received at the ARB **no later than 12:00 noon, February 20, 2001**.

The Board requests but does not require that 30 copies of any written statement be submitted and that all written statements be filed at least 10 days prior to the hearing so that ARB staff and Board Members have time to fully consider each comment. The ARB encourages members of the public to bring to the attention of staff in advance of the hearing any suggestions for modification of the proposed regulatory action.

STATUTORY AUTHORITY AND REFERENCES

This regulatory action is proposed under that authority granted in Health and Safety Code, sections 39600, 39601, 43013, 43018, 43101, and 43806. This action is proposed to implement, interpret and make specific sections California Health and Safety Code sections 39000, 39001, 39002, 39003, 39010, 39500, 40000, 43000, 43013, 43016, 43018, 43100, 43101, and 43806.

HEARING PROCEDURES

The public hearing will be conducted in accordance with the California Administrative Procedure Act, Title 2, Division3, Part 1, Chapter 3.5 (commencing with section 11340) of the Government Code.

Following the public hearing, the Board may adopt the regulatory language as originally proposed or with non substantial or grammatical modifications. The Board may also adopt the proposed regulatory language with other modifications if the text as modified is sufficiently related to the originally proposed text that the public was adequately placed on notice that the regulatory language as modified could result from the proposed regulatory action; in such event the full regulatory text with the modifications clearly indicated, will be made available to the public, for written comment at least 15 days before it is adopted.

The public may request a copy of the modified regulatory text from the ARB's Public Information Office, Air Resources Board, 1001 "I" Street, Environmental Services Center, 1st Floor, Public Information Office, Sacramento, CA 95814, (916) 322-2990.

CALIFORNIA AIR RESOURCES BOARD

Michael P. Kenny
Executive Officer

Date: December 11, 2001

The energy challenge facing California is real. Every Californian needs to take immediate action to reduce energy consumption. For a list of simple ways you can reduce demand and cut your energy costs see our Web –site at www.arb.ca.gov.

California Environmental Protection Agency

Air Resources Board

Proposed Amendments to the California Alternative Fuels for Motor Vehicle Regulations

Proposed Amendments to the Compressed Natural Gas and Liquefied Petroleum Gas Specifications in the Alternative Fuels for Motor Vehicle Regulations

STAFF REPORT: INITIAL STATEMENT OF REASONS

TITLE 13. CALIFORNIA AIR RESOURCES BOARD

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COSTS TO PUBLIC AGENCIES AND TO BUSINESSES AND PERSONS AFFECTED

The determinations of the Board's Executive Officer concerning the costs or savings necessarily incurred in reasonable compliance with the proposed regulations are presented below.

The Executive Officer has determined that the proposed regulatory action will not create costs or savings, as defined in Government Code section 11346.5(a)(6), to any state agency or in federal funding to the state, costs or mandate to any local agency or school district whether or not reimbursable by the state pursuant to Part 7 (commencing with section 17500), Division 4, Title 2 of the Government Code, or other non-discretionary savings to local agencies.

In developing this regulatory proposal, the ARB staff evaluated the potential economic impacts on representative private persons or businesses. The ARB is not aware of any cost impacts that a representative private person or business would necessarily incur in reasonable compliance with the proposed action. Representative private persons will not be affected by cost impacts for this proposed regulation.

The Executive Officer has made an initial determination that the proposed regulatory action will not have a significant statewide adverse economic impact directly affecting businesses, including the ability of California businesses to compete with businesses in other states, or on representative private persons.

In accordance with Government Code section 11346.3, the Executive Officer has determined that the proposed regulatory action will not affect the creation or elimination of jobs within the State of California, the creation of new businesses or elimination of existing businesses within the State of California, or the expansion of businesses currently doing business within the State of California. A detailed assessment of the economic impacts of the proposed regulatory action can be found in the Staff Report (ISOR).

The Executive Officer has also determined, pursuant to Government Code section 11346.5(a)(3)(B), that the proposed regulatory action will not affect small businesses because this is a change to a regulation that is voluntary with respect to small businesses and there are no mandated requirements and no associated impacts.

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Air Resources Board
1001 "I" Street, 23rd Floor
Sacramento, California 95814

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STATUTORY AUTHORITY AND REFERENCES

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HEARING PROCEDURES

The public hearing will be conducted in accordance with the California Administrative Procedure Act, Title 2, Division3, Part 1, Chapter 3.5 (commencing with section 11340) of the Government Code.

Following the public hearing, the Board may adopt the regulatory language as originally proposed or with non substantial or grammatical modifications. The Board may also adopt the proposed regulatory language with other modifications if the text as modified is sufficiently related to the originally proposed text that the public was adequately placed on notice that the regulatory language as modified could result from the proposed regulatory action; in such event the full regulatory text with the modifications clearly indicated, will be made available to the public, for written comment at least 15 days before it is adopted.

The public may request a copy of the modified regulatory text from the ARB's Public Information Office, Air Resources Board, 1001 "I" Street, Environmental Services Center, 1st Floor, Public Information Office, Sacramento, CA 95814, (916) 322-2990.

CALIFORNIA AIR RESOURCES BOARD

Michael P. Kenny
Executive Officer

Date: December 11, 2001

The energy challenge facing California is real. Every Californian needs to take immediate action to reduce energy consumption. For a list of simple ways you can reduce demand and cut your energy costs see our Web –site at www.arb.ca.gov.

State of California
California Environmental Protection Agency
AIR RESOURCES BOARD
Stationary Source Division

STAFF REPORT: INITIAL STATEMENT OF REASONS PROPOSED AMENDMENTS TO THE ALTERNATIVE FUELS FOR MOTOR VEHICLE REGULATIONS

Public Hearing to Consider Amendments to the California Alternative Fuel Regulations

Date of Release: December 21, 2001
Scheduled for Consideration: February 21, 2002

Location:

California Air Resources Board
Central Valley Auditorium, 2nd Floor
1001 I Street
Sacramento, California 95814

This report has been reviewed by the staff of the Air Resources Board and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Air Resources Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. To obtain this document in an alternative format, please contact the Air Resources Board ADA Coordinator at (916) 322-4505, TDD (916) 324-9531, or (800) 700-8326 for TDD calls from outside the Sacramento area. This report is available for viewing or downloading from the Air Resources Board's Internet site; **http://www.arb.ca.gov/regact/cng-lpg/cng-lpg.htm**

Acknowledgments

This report was prepared with the assistance and support from the other divisions and offices of the Air Resources Board. In addition, we would like to acknowledge the assistance and cooperation that we have received from many individuals and organizations. In particular, we would like to thank members of the California Energy Commission, Southern California Gas Company, Clean Air Vehicle Technology Center, Engine Manufacturers Association, California Independent Petroleum Association, Independent Oil Producers' Agency, and the Western States Petroleum Association.

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Dean C. Simeroth, Chief, Criteria Pollutants Branch
Gary M. Yee, Manager, Industrial Section

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I. Executive Summary

A. Introduction

This report is the Initial Statement of Reasons for the proposed amendments to sections 2292.5 – 2292.6, Title 13, California Code of Regulations. Section 2292.5 contains specifications for compressed natural gas (CNG) sold for motor vehicle use, while section 2292.6 contains the motor vehicle liquefied petroleum gas (LPG) specifications. Section 2291 prohibits the sale or supply of motor vehicle CNG and LPG in California that does not meet the specifications contained in sections 2292.5 and 2292.6. This summary first discusses the proposed amendments for CNG and the second part discusses the proposed amendments for LPG.

A previous report regarding the CNG and LPG specifications was published in 1991[1]. Additional reports regarding LPG were published in 1994[2], 1997[3], and 1998[4].

B. Compressed Natural Gas

1. Summary of Proposed CNG Amendments

a. Why is staff proposing amendments to the alternative fuels regulations for CNG?

Staff is proposing amendments to the alternative fuels regulations for CNG to increase compliance flexibility and the availability of complying motor vehicle CNG in California.

The current CNG fuel specifications consist of a set of prescriptive limits that restrict flexibility in complying with the CNG fuel specifications. Due to these narrow limits, much of the CNG produced in the Southern San Joaquin Valley and the South Central Coast does not comply with the CNG fuel specifications. The reason for this is because natural gas produced in these regions is produced in association with oil production where oil constituents can contaminate the natural gas, thus making the natural gas out of specification. In other parts of the State, natural gas is either imported or produced from gas wells (not associated with oil) where the natural gas is relatively clean and meets the CNG fuel specifications.

b. How do the proposed amendments provide more compliance flexibility?

In the past, engine manufacturers and the natural gas industry have used the specific composition of CNG to evaluate CNG fuel quality and its effect on engine performance and emissions. However more recently, engine manufacturers have developed indices such as methane number and Wobbe Index to assess CNG fuel quality. These indices do not specifically limit the compositional make-up of CNG but establishes performance thresholds for which engines can properly operate. Therefore, proposing a CNG fuel specification by one of these indices (e.g. methane number) would provide additional compliance flexibility and increase the availability of compliant CNG.

Engine manufacturers have also developed new technology engines that can operate on wider variations in CNG fuel quality. These new technology engines are equipped with advanced feedback control systems that compensate for varying fuel quality; thus allowing the engine to operate on a wide range of CNG composition. In comparison to the existing CNG fuel specifications, these engines can expand the CNG compositional range that would be acceptable for proper engine operation. Therefore, proposing an alternative CNG specification in recognition of new advance technology engines would also allow additional compliance flexibility and increase the availability of compliant CNG.

c. What is Methane Number and why is it necessary?

Methane number (MN) for CNG is similar to the octane number used in gasoline. Like octane number, MN provides an indication of the knock tendency of the fuel. MN can be calculated from the fuel composition as demonstrated in Appendix D. The primary benefit from using MN is the flexibility it provides in allowing the CNG composition to vary. A producer can improve gas quality by choosing which fuel components to remove. The heavier or higher carbon chain components are easier to remove and have more of an adverse influence on the MN than the lighter components. Thereby a reduction of the heavier components will have a larger positive impact on the MN (resulting in an improvement in gas quality) than the lighter components.

d. What amendments to the alternative fuels regulations are being proposed?

Staff is proposing that a statewide CNG methane number (MN) specification of at least 80 be added as an alternative to the existing CNG specifications. This provision would allow the CNG producers and providers more flexibility to comply with the regulations while ensuring that engine performance and emissions will not be affected.

In addition, staff is proposing an alternative CNG specification of MN 73 for CNG fueling facilities in the Southern San Joaquin Valley (SSJV) and the South Central Coast (SCC) that meet the following criteria:

1) The natural gas service provider does not provide natural gas that meets an MN of 80 at the service connection;

2) The vehicles fueled at the facility are recommended by the engine manufacturer as being able of operating on CNG with a MN of 73; and

3) The fueling station has controls in place to prevent misfueling.

2. Effects of the Proposed CNG Amendments

a. Who will be affected by the amendments?

Producers, gas companies, fuel station owners, fleet owners, and vehicle owners will all benefit from the proposed CNG amendments. The proposed amendments will provide flexibility and increase the supply of motor vehicle CNG.

b. How will the proposed amendments affect fuel quality?

The existing CNG specifications equate to a MN of about 81 and are almost equivalent to the proposed MN 80 specification. The MN 80 specification represents a minimum fuel quality specification recommended by engine manufacturers that is protective of existing and future technology engines.

The proposed MN 73 specification is significantly different than the existing CNG fuel specifications and represents a broader range of fuel quality. Engine manufacturers recognize that advanced and future technology engines can and would be able to properly operate on a MN 73 specification without significantly affecting emissions and with no impact on engine performance and durability. The proposed MN 73 specification will be limited to advanced and future technology engines in the SSJV and SCC. The MN 73 specification is not recommended for the SCAQMD as the extensive CNG fleet has too many of the older technology vehicles to allow for the dual approach. The additional flexibility is not needed in the remainder of the State as the CNG is from imported natural gas, which is very high quality.

c. How will the proposed amendments affect the availability of fuel?

The proposed amendments for CNG will provide more flexibility for the natural gas suppliers including producers to comply with the motor vehicle CNG fuel specifications. By providing additional compliance options, the proposed amendments allow gas suppliers to tailor modifications to their facilities, which will enable easier compliance with the specifications; thereby increasing the availability of motor vehicle grade CNG fuel.

d. How will these proposed amendments affect engine performance?

Engine manufacturers recommend that open loop and first generation closed loop technology CNG engines utilize fuel that meets a minimum MN of 80. This specification allows these engines to properly operate and maintain performance. Advanced technology closed loop engines are equipped with improved feedback controls which allow these engines to operate on a broader range of fuel quality. Engine manufacturers believe that advanced technology engines can properly operate on CNG with a MN of 73.

3. Regulatory Development Process and Evaluation of Alternatives

a. What process did the ARB staff use to develop the proposed amendments?

The staff developed the proposed CNG amendments with the participation of stakeholders that included the Southern California Gas Company (SoCalGas), natural gas producers, vehicle fleet owners, CNG fueling station owners, and engine manufacturers. The Engine Manufacturers Association (EMA), Western States Petroleum Association (WSPA), California Independent Producers Association (CIPA) and the Independent Oil Producers Association (IOPA) were instrumental in coordinating the participation of their respective members.

Several joint industry meetings were conducted in addition to individual meetings and teleconferences with the SoCalGas, the producer associations and the engine manufacturers. The staff worked with SoCalGas to discuss existing and potential compliance options to meet the current CNG specifications. Staff also held conference calls with individual engine manufacturers to discuss engine technologies and fueling requirements for the vehicles. Staff met and discussed with the producer associations and individual natural gas producers to evaluate the processing capabilities of production sites.

Staff plans to conduct a public workshop after the release of the staff report to discuss the proposed amendments to the CNG motor vehicle fuel specifications.

b. What other alternatives were evaluated?

The CNG amendments are being proposed to add more flexibility and increase the supply of these fuels for motor vehicles. The alternative would be to not amend the existing regulations.

4. Compliance with the Proposed CNG Amendments

a. How is the industry complying with the current CNG standards?

Less than one percent of the natural gas used in the State is compressed and used as CNG motor vehicle fuel. Most of the pipeline gas used to produce CNG in the State complies with the motor vehicle fuel specifications. However, about ten percent of the pipeline gas used to produce CNG does not comply with these fuel specifications. This non-complying fuel is primarily found in areas that have natural gas production associated with oil production. These areas are in the SSJV, SCC, and parts of the Los Angeles Basin.

In the SSJV and the SCC, SoCalGas is blending the pipeline natural gas with trucked in high quality methane at about seven CNG fueling stations to ensure that the CNG supplied to motor vehicles meets the fuel specifications. A blend gas transport vehicle delivers high quality methane to the fueling stations on a weekly basis. This blend gas is mixed with the pipeline gas at the time of fueling. As discussed in Chapter IV, SoCalGas's ability to manage the fueling stations is limited by the blending gas transport vehicle and the local restrictions at the blend gas production site.

In the Los Angeles Basin, local produced associated gas is diluted with high quality gas in the pipeline and has not required blending at the fueling stations. However, due to changes in the State's natural gas demand, more gas from the SSJV is being shipped south into the Los Angeles Basin. Industry is currently evaluating several mitigation measures to ensure that natural gas used for motor vehicles in the Los Angeles Basin complies with the specifications. These include additional processing by producers and blending in the gas company distribution system.

b. Can the industry continue to comply by blending CNG at fueling facilities?

The current practice of blending has several drawbacks, and is not the most desirable option for an extended period.

SoCalGas is operating a unique blend truck, which can take uncompressed natural gas and compress it as it loads. This enables them to transport a larger quantity of gas per load. In addition, this truck can maintain the compression as it off loads the gas into storage tanks. The current process can only service seven fueling stations.

In addition, county restrictions at the gas site that produces the blend gas limit the number of loads per day. Therefore, no additional fueling stations can be serviced with high quality gas from this site. SoCalGas has over twenty applications for additional fueling stations that are currently on hold. The proposed amendments would provide the needed supply of motor vehicle

CNG fuel for these additional fueling sites to operate, thus allowing the CNG vehicle fleet to expand.

c. Are the proposed specifications technologically and commercially feasible?

Yes, the proposed amendments are technologically and commercially feasible. The proposed CNG amendments add compliance flexibility to the regulations and are not mandatory. The existing fuel specifications are not affected and may be still used in place of the alternative specifications. Measures to comply with the existing fuel specifications can be used to meet the proposed amendments.

d. Do the proposed amendments affect the motor vehicle certification fuel?

The proposed amendments do not affect the certification fuel specifications, nor how engine manufacturers comply with engine certification standards.

e. How will CNG fueling stations comply with the proposed standards?

The proposed amendments are optional and do not impose additional requirements beyond those in the current regulation; in fact the proposed amendments provide additional compliance flexibility. Currently, fueling station owners need to ensure that their stations provide CNG that meets the CNG fuel specifications. The current fuel specifications are approximately equivalent to the proposed CNG MN 80 specification. However, due to the non-complying status of some of the CNG produced in the SSJV and SCC, industry will need to continue to take affirmative efforts to provide a source of complying CNG.

The industry is considering several measures to provide complying CNG. As mentioned, gas blending at fueling stations has been used, but may have logistic issues that would limit its wide application and long term feasibility. SoCal Gas has also used in-pipeline blending to improve the quality of natural gas, but this is limited by the pipeline infrastructure and availability of high quality pipeline gas for blending.

Recently, some producers are now evaluating gas treatment options that would improve gas quality at the producers level. Some producers are considering moderate to major gas treatment improvements depending on their current facility configurations and volume of gas production. Also being considered is the repowering of older CNG vehicles in the SSJV and SCC. This would lessen the need to treat all of the gas produced in the SSJV and SCC. Staff estimates that if most of the major gas producers met the proposed MN 80 specifications, gas quality in the SSJV, SCC, and the Los Angeles Basin would be maintained at a level to be protective of existing and new CNG vehicles, without significant effort on the part of small producers.

f. What should be considered when siting future CNG fueling stations to avoid gas quality issues?

The proposed amendments would establish a CNG specification of MN 80 statewide and a MN 73 option in a limited region in California. Generally, while the vast majority of potential sites will not have any fuel quality issues, potential fleet operators should coordinate with their gas provider to determine the quality of fuel that is available. Staff has identified small pockets of gas production in the Los Angeles Basin that do not meet the MN 80 specification. This gas production does not currently affect existing CNG fueling stations, but can potentially impact future fueling stations if located in the close proximity of these pockets. Thus, potential fleet operators in coordination with the gas provider should consider the quality of gas available in selecting future fueling sites.

For the region where the MN 73 option is allowed, potential fleet operators should coordinate with their gas service provider to determine the quality of fuel that is available and the appropriate technology vehicles that can be fueled with the fuel.

g. How will the ARB enforce the Alternative Fuels Regulations?

The proposed amendments will not change the ARB's enforcement practice. ARB enforcement staff will test the fuel at the fueling stations, to determine compliance. If the fuel is being used to fuel motor vehicles and does not comply with the motor vehicle specifications, ARB staff will attempt to determine which of the parties that are responsible for supplying the fuel that is in violation of the alternative fuels regulations.

5. Impacts of the Proposed CNG Amendments

a. Emission Impacts

1) How will the proposed amendments affect exhaust emissions?

Test results show that for dedicated light-duty NGVs, large variations in fuel composition produced only slight variations, both increases and decreases, in emissions and driveability. Also, bi-fuel vehicles had only modest changes in emissions and performance with changes in CNG quality.[5, 6] Heavy-duty vehicle test data shows that fueling advanced generation engine technologies with MN73 fuel produces no discernible impact on the particulate matter (PM) and oxides of nitrogen (NOx) emissions when compared to emissions from higher quality fuels with MN greater than 80. There were very small increases in carbon dioxide (CO_2) and non-methane hydrocarbon (NMHC) emissions.

2) How do CNG exhaust emissions compare to diesel exhaust emissions?

Typical in-use diesel PM emissions from buses without after-treatment represent a three- to five-fold increase over typical PM emissions from CNG buses using compliant motor vehicle fuel. On average, NOx emissions from diesel buses are greater than NOx emissions from CNG buses.[7]

3) What potential emissions impacts may result if the proposed amendments are not adopted?

The limited availability of motor vehicle grade CNG in the SSJV and SCC has resulted in the potential conversion of several diesel fleets to CNG fleets and fueling sites being postponed. In some cases, proponents have elected to remain with diesel vehicles since there is no certainty in the availability of motor vehicle grade CNG in these regions. In cases where diesel is elected over CNG vehicles, exhaust emissions of NOx and PM will be likely higher.

The amendments should help make CNG more widely available for vehicles, thus enabling greater use of CNG vehicles. Such greater use would reduce emissions because, overall, CNG fueled vehicles emit less than the diesel vehicles they replace.

b. Economic Impacts

1) What economic impact do the proposed amendments create?

There will be no new mandated costs associated with the proposed amendments to the CNG motor vehicle specifications. These amendments provide additional flexibility to the specifications and allow more cost effective options to comply with the regulations. The proposed amendments for CNG will facilitate further expansion of CNG fueling sites and CNG vehicles.

Although the proposed amendments do not directly impose new costs to industry, there will likely be costs associated with industry ensuring that the quality of fuel that is shipped to the Los Angeles Basin meets an MN 80 specification. As discussed earlier, some gas producers are considering gas treatment options to improve the quality of the gas. These options will have cost associated with their implementation.

c. Environmental Impacts

1) What impact do the proposed amendments have on public health and the environment?

The proposed amendments to the CNG motor vehicle fuel specifications would cause no significant adverse impact to either the public health or the environment.

As discussed earlier, the proposed CNG amendments will not significantly impact motor vehicle exhaust emissions from vehicles now using CNG. The proposed amendments would allow more variability in the motor vehicle CNG fuel formulations, but the fuel constituents and fuel processing methods already in use would remain the same. The proposed amendments would allow gas producers to shift the ratio of fuel constituents while still maintaining a minimum methane number. More of some constituents would be allowed to remain in the motor vehicle fuel rather than be extracted and added to another fuel (e.g., LPG). Therefore, there is no increase or decrease in fuel constituents that are released to the environment (e.g., air, water, or land).

2) Do the proposed amendments affect the commitments in the SIP?

The proposed CNG amendments will not have any impact on the State Implementation Plan measures because these fuel specifications are not a SIP strategy.

3) How will the proposed amendments affect greenhouse gases?

The CNG amendments are not expected to significantly increase emissions of greenhouse gases (GHG). Although there is a small increase in carbon dioxide emissions from using MN 73 versus MN 80, the use of MN 73 CNG is expected to be minimal since most of the CNG produced in the SSJV and the SCC is anticipated to comply with MN 80 CNG specification. Therefore, no significant impact on GHG is expected from the proposed amendments.

6. Future CNG Activities

The proposed CNG amendments provide increased compliance flexibility that will increase the availability of motor vehicle grade CNG. This will facilitate the continued use and expansion of the existing CNG fleets, maintain the emissions benefits of CNG vehicles, and improve the expansion of the CNG market. However, to address the need for future emission control strategies to meet the federal and State ambient air quality standards, it may be necessary in the future to re-evaluate the CNG motor vehicle fuel specifications. Specifically, future motor vehicle exhaust emissions standards may require the cleanest fuels available. Therefore, CNG as well as other alternative fuels may need to be further refined to accommodate future engine technologies and vehicle exhaust emission standards.

C. Liquefied Petroleum Gas

1. Summary of Proposed LPG Amendments

a. Why is staff proposing amendments to the alternative fuels regulations for LPG?

Staff is proposing amendments to the alternative fuels regulations for LPG to increase compliance flexibility. In Northern California, the quality of LPG varies significantly and ranges from LPG meeting the commercial specifications (residential and commercial use) to LPG meeting the more stringent motor vehicle fuel specifications. Because both fuels are handled in a single distribution system, issues arise regarding the delivery of these fuels in small transport trucks ("bobtails") that operate on the same fuel as they deliver. In the case where the delivery fuel does not meet the motor vehicle fuel specifications, the use of this fuel to operate the truck may be in violation of the LPG motor vehicle specifications in the alternative fuels regulations.

Discussions with LPG distributors regarding the historical use of non-motor vehicle LPG in bobtails indicates that bobtails experience satisfactory engine performance although some higher engine maintenance may exist with using off-specification LPG fuel. LPG distributors have long accepted possible increased service frequencies and recognize the potential invalidation of engine warranties may result with the use of off-specification LPG fuel.

b. What amendments to the alternative fuels regulations are being proposed?

Staff is proposing to add an exemption for LPG delivery vehicles that deliver and operate on the same LPG cargo fuel. These vehicles would be allowed to operate on commercial grade or motor vehicle grade LPG. -

2. Effects of the Proposed LPG Amendments

a. Who will be affected by the amendments?

The proposed LPG amendments will aid the marketers, suppliers, retailers, and end-users by allowing bobtails to operate without violating the motor vehicle LPG specifications.

b. How will the proposed amendments affect fuel quality?

The proposed exemption from the LPG motor vehicle specifications applies only to bobtail trucks used to transport LPG to distribution and marketing facilities. Bobtails are small transport trucks that operate on the cargo fuel. This exemption will only affect the fuel quality that bobtail vehicles use. All other vehicles are required to operate on LPG that meets the motor vehicle fuel specifications. Bobtail vehicles would therefore be allowed to run on either commercial or motor vehicle grade LPG.

c. How will the proposed amendments affect the availability of fuel?

The proposed LPG amendments will facilitate the delivery of commercial LPG fuel to non-motor vehicle accounts. However, the proposed amendments will have no effect on the supply of motor vehicle LPG fuel.

d. How will these proposed amendments affect engine performance?

Bobtails in Northern California have been satisfactorily operating on commercial grade LPG fuel for the last ten years. The proposed amendments would not change the current operational practices of bobtail owners. Although engine manufacturers believe that additional maintenance may be necessary for vehicles operating on commercial grade fuel due to potential injector and vaporizer deposits, only a few fleet owners indicate that increased maintenance is necessary. Many fleet owners operate bobtails in both Northern and Southern California. Fleet owners claim that when comparing their Northern California and Southern California bobtail truck engines (Southern California vehicles typically operate on motor vehicle grade LPG), the Northern California bobtail engines have not experienced any increased performance or durability problems. [8]

3. Regulatory Development Process and Evaluation of Alternatives

a. What process did the ARB staff use to develop the proposed amendments?

The staff developed the proposed LPG amendments with the participation of several stakeholders that included vehicle fleet owners, LPG fueling station owners, engine manufacturers, refineries, LPG brokers, and LPG suppliers.

Staff held numerous teleconferences and meetings with refiners to discuss their ability to comply with the motor vehicle LPG specifications and how future refinery modifications may impact compliance. The staff held several conference calls and meetings with the associations, LPG suppliers, and brokers to understand the limitations of the current LPG distribution system.

Staff held a public workshop at the start of the process to solicit comments and identify stakeholders. Staff plans to conduct a second public workshop after the release of the staff report to discuss the proposed amendments to the LPG motor vehicle fuel specifications.

b. What other alternatives were evaluated?

The LPG amendments are being proposed to add more flexibility and increase the supply of these fuels for motor vehicles. The alternative would be to not amend the existing regulations.

4. Compliance with the Proposed LPG Amendments

a. How is the industry complying with the current LPG standards?

Southern California refineries generally comply with the LPG motor vehicle fuel specifications, but in Northern California, only one refinery consistently complies. Of the four remaining Northern California refineries, only two are currently selling LPG (with quality ranging from commercial to motor vehicle grade LPG), one refiner is using its LPG onsite, and the other is not producing LPG at all. Also, LPG produced from gas plants and imported LPG generally meet the motor vehicle fuel specifications.

While most large transport trucks have cargo tanks and separate fuel tanks from which they operate, many of the some smaller transport trucks, "bobtails", operate on the same cargo fuel they carry. Bobtails typically transport LPG from intermediate storage facilities to the end-users (e.g. residential users, industrial/commercial users, and agricultural users). Many of the end users are in rural areas that are not accessible by the larger transport trucks and can only be supplied by bobtails. Since Northern California refineries produce both commercial and motor vehicle LPG and the industry's infrastructure is not designed with dual fuel storage capability, bobtails may intermittently operate on commercial grade LPG when delivering fuel to non-motor vehicle accounts.

Staff has been working with the industry to evaluate several options available to facilitate compliance. However, based on the limited availability of complying motor vehicle grade LPG in Northern California, equipping bobtails with separate fuel tanks would not ensure compliance. Thus, staff is proposing an exemption for these delivery trucks. If the proposed amendments are not adopted, bobtails would likely be converted to operate on diesel fuel. As discussed in section 5.a, conversion to diesel would increase PM emissions beyond that experienced from bobtails operating on commercial grade LPG fuel.

5. Impacts of the Proposed LPG Amendments

a. Emission Impacts

1) How will the proposed amendments affect exhaust emissions?

Test results with LPG heavy-duty vehicles show that off-specification LPG (20 percent propene as compared to the LPG specification of 10 percent propene) will increase NOx emissions by about 14 percent when compared to motor vehicle grade LPG. This increase, however, is still within original vehicle emission certification standards since these vehicles were originally certified on diesel. There is no significant impact on other emissions.

2) How do LPG exhaust emissions compare to diesel exhaust emissions?

Most LPG bobtails were originally certified to diesel engine certification emissions standards. Although potentially cleaner, the overall ozone forming potential of the emissions from LPG bobtail conversions are comparable to their diesel counterparts. However, PM emissions from LPG bobtails are significantly lower than from diesel vehicles.

3) What potential emissions impacts may result if the proposed amendments are not adopted?

If LPG bobtail delivery trucks are not allowed to operate on commercial LPG, these trucks will need to be equipped with separate fuel tanks to run on a legal motor vehicle fuel. Although motor vehicle grade LPG would be the preferable fuel, gasoline or diesel fuel would likely be chosen due to the limited availability of complying LPG. In this case, running on gasoline or diesel fuel would likely increase emissions.

b. Economic Impacts

1) What economic impact do the proposed amendments create?

There will be no new costs associated with the proposed amendments to the LPG motor vehicle specifications. These amendments provide additional flexibility to the specifications and allow a more cost effective option to comply with the regulations.

c. Environmental Impacts

1) What impact do the proposed amendments have on public health and the environment?

The proposed amendments to the LPG motor vehicle fuel specifications would cause no significant adverse impact to either the public health or the environment.

The proposed amendments to the LPG motor vehicle fuel specifications would not change either fuel constituents or fuel processing methods. It would allow bobtail delivery vehicles to use commercial and motor vehicle grade LPG. As discussed, the use of commercial LPG in these vehicles could result in a moderate increase in NOx emissions. However considering there are only about 500 bobtail delivery trucks in Northern California that are likely to use commercial LPG intermittently, staff believes there would be little impact on public health or the environment.[8] As discussed earlier, if these vehicles are not allowed to run on commercial LPG, they would likely convert back to gasoline or diesel fuel and would increase emissions above existing levels.

2) *Do the proposed amendments affect the commitments in the SIP?*

The proposed LPG amendments will not have any impact on the State Implementation Plan measures because these fuel specifications are not a SIP strategy.

3) *How will the proposed amendments affect greenhouse gases?*

The LPG amendments are not expected to significantly increase emissions of greenhouse gases (GHG). Therefore no significant impact on GHG is expected from the proposed amendments.

II. Recommendation

The staff recommends that the Board adopt the proposed amendments to the Board's alternative fuel regulations as contained in Appendix A with the recognition that staff may propose some modifications to the proposal based on information and comments obtained subsequent to the release of the Staff Report and prior to the Board hearing in February 2002.

III. Background

This section provides background on the alternative fuels regulations.

A. Alternative Fuels Regulations

The ARB alternative fuels regulations, adopted in 1992, include specifications for seven alternative fuels that are shown below:

- M-100 (100 volume percent methanol)
- M-85 (Nominally 85 volume percent methanol and 15 volume percent unleaded gasoline)
- E-100 (100 volume percent ethanol)
- E-85 (Nominally 85 volume percent ethanol and 15 volume percent unleaded gasoline)
- CNG (Compressed Natural Gas)
- LPG (Liquefied Petroleum Gas)
- Hydrogen

The regulations include specifications for certification fuels for certifying new vehicles and specifications for commercial fuels for in-use vehicles. The specifications were developed in anticipation that alternative fuels would be used by engine manufacturers to design vehicles to meet the increasingly stringent low emission vehicle (LEV) standards. The certification specifications provide engine manufacturers with fuel quality specifications to design and certify engines. The commercial specifications (which are the sole subject of the proposed amendments) define the fuel that is used by motor vehicles operated in California. The commercial specifications ensure that in-use fuels are similar to the fuels used to certify new vehicles and engines, and to ensure the fuel quality in the market place to protect engines and maintain the emissions benefit of alternative fuels. The following sections discuss the commercial CNG and LPG motor vehicle specifications.

B. Compressed Natural Gas

The motor vehicle specifications for CNG were developed in consultation with the natural gas industry, the automobile industry, the engine manufacturers, and other interested parties. The specifications developed were based on a consensus of the quality of natural gas that was imported and produced in California. The motor vehicle CNG specifications are contained in the California Code of Regulations (CCR), title 13, section 2292.5 and are shown in Table III-1. The CNG specifications have not been amended since their original adoption.

Table III-1: Motor Vehicle CNG Specifications

Specifications		Value
Hydrocarbons (expressed as mole percent)	Methane	88.0% (min.)
	Ethane	6.0% (max.)
	C3 and higher HC	3.0% (max.)
	C6 and higher HC	0.2% (max.)
Other Species (expressed as mole percent unless otherwise indicated)	Hydrogen	0.1% (max.)
	Carbon Monoxide	0.1% (max.)
	Oxygen	1.0% (max.)
	Inert Gases (Sum of CO_2 and N2)	1.5-4.5% (range)
	Sulfur	16 ppmv (max.)
	Water	a
	Particulate Mater	b
	Odorant	c
[a]The dewpoint at vehicle fuel storage container pressure shall be at least 10°F below the 99.0% winter design temperature listed in Chapter 24, Table 1, Climatic Conditions for the United States, in the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook, 1989 fundamentals volume. Testing for water vapor shall be in accordance with ASTM D 1142-90, utilizing the Bureau of Mines apparatus.		
[b]The compressed natural gas shall not contain dust, sand, dirt, gums, oils, or other substances in an amount sufficient to be injurious to the fueling station equipment or the vehicle being fueled.		
[c]The natural gas at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air or not over 1/5 (one-fifth) of the lower limit of flammability.		

C. Liquefied Petroleum Gas

Like other alternative fuel specifications, the motor vehicle specifications for LPG were adopted in consultation with the LPG industry, automobile industry, the engine manufacturers, and other interested parties. The specifications were developed using two established references as guides. The first is the Gas Producers Association (GPA) Standard 2140, which contains recommended specifications for motor vehicle LPG fuel (referred to as "heavy-duty-5" or HD-5). These specifications require a fuel composition of "not less than 90 liquid volume percent propane…[and] not more than 5.0 liquid volume percent propene." The second reference is the American Society of Testing and Materials (ASTM) Designation D1835-89, which has set specifications for "special-duty LPG" to be consistent with the HD-5 specifications set by the GPA.

When the regulations were adopted, the Board set an interim limit of 10.0 volume percent propene and a minimum 80.0 volume percent propane content requirement, applicable from

January 1, 1993 through December 31, 1994. Starting on January 1, 1995, the propene content is limited to a maximum value of 5.0 volume percent and the minimum propane content is increased to 85.0 volume percent. Thus, the Board's specifications for LPG for use in vehicles is very similar to HD-5, differing only in the minimum propane content. The Board adopted the 5.0 volume percent propene requirement to limit the reactivity of exhaust emissions because propene is more reactive in the atmosphere than propane. However, the Board provided a two-year delay because LPG fuel proponents expressed concerns that LPG fuel meeting the 5.0 volume percent propene requirement would not immediately be available.

In 1994, the Western Propane Gas Association (WPGA) petitioned the Board to continue the interim 10 volume percent propene requirement because of concern that there was no reliable supply of 5 volume percent propene fuel. In response, the Board continued the interim 10 volume percent propene requirement until January 1, 1997. Then again in 1996, the WPGA petitioned the Board a second time to further continue the interim propene requirement because of similar supply issues. In response, the Board in 1997 extended the interim requirement until January 1, 1999. In making the second delay of the 5 volume percent propene requirement, the Board stated its intent to grant no further delays. It instructed the staff to seek an alternative to the specifications in section 2292.6 to take effect in 1999 that would provide satisfactory emission control, provide good performance in LPG engines, and be more likely to be met by the LPG produced in the market.

In 1998, the Board adopted the 10 volume percent propene limit as a permanent alternative to the LPG specifications in CCR, title 13, section 2292.6, effective January 1, 1999 after engine test results show minimal emissions increased between a 5 volume percent propene fuel and a 10 volume percent propene fuel. The current motor vehicle LPG specifications are shown in Table III-2. The Board acted to preserve and enhance the current supply of complying fuel to owners of LPG vehicles and to assure adequate emissions performance.

Table III-2: Motor Vehicle LPG Specifications

Specifications	*Value*	*Test Method*
Propane	85.0 vol. % (min.) a/	ASTM D 2163-87
Vapor Press. at 100° F	208 psig (max.)	ASTM D 1267-89 ASTM D 2598-88 b/
Volatility residue: Evaporated temp., 95% or butanes	 -37° F (max.) 5.0 vol. % (max.)	 ASTM D 1837-86 ASTM D 2163-87
Butenes	2.0 vol. % (max.)	ASTM D 2163-87
Pentenes, and heavier	0.5 vol. % (max.)	ASTM D 2163-87
Propene	10.0 vol. % (max.)	ASTM D 2163-87
Residual matter: Residue on evap. of 100 ml Oil stain observed.	 0.05 ml (max.) pass c/	 ASTM D 2158-89 ASTM D 2158-89
Corrosion, copper strip	No. 1 (max.)	ASTM D 1838-89
Sulfur	80 ppmw (max.)	ASTM D 2784-89
Moisture content	pass	ASTM D 2713-86
Odorant	d/	

a/ Propane shall be required to be a minimum of 80.0 volume percent starting on January 1, 1993. Starting on January 1, 1997, the minimum propane content shall be 85.0 volume percent.

b/ In case of dispute about the vapor pressure of a product, the value actually determined by Test Method ASTM D 1267-89 shall prevail over the value calculated by Practice ASTM D 2598-88.

c/ An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper, in 0.1 ml increments and examined in daylight after 2 min. as described in Test Method ASTM 2158-89.

d/ The liquefied petroleum gas upon vaporization at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air of not over 1/5 (one-fifth) of the lower limit of flammability.

D. Comparable Federal Regulations

There are no other legally enforceable specifications for CNG and LPG motor vehicle fuels in the United States. The United States Environmental Protection Agency does not have any specifications for motor vehicle CNG and LPG. The Board's specifications for CNG and LPG for use in motor vehicles, as presented in the previous discussion, are the only required specifications for motor vehicle CNG and LPG, respectively.

E. Commercial Standards

In addition to use as motor vehicle fuels, natural gas and LPG are used in industrial, commercial and residential applications. The gas quality for these applications is referred to as commercial grade. The industry has developed fuel standards for commercial grade natural gas and LPG.

There are four general standards that apply to commercial natural gas. These standards were developed mainly for safety reasons. Two of the four are recommended practices and include:

- Society of Automotive Engineers (SAE) J1616, "Recommended Practice for Compressed Natural Gas Vehicle Fuel," issued in February 1994

- National Fire Protection Association (NFPA) 52, "Compressed Natural Gas (CNG) Vehicular Fuel Systems 1992 Edition," issued August 1992.

SAE J1616 and NFPA 52, apply to the design and installation of CNG vehicle fuel systems and fueling dispensing systems.

The other two standards include:

- California Public Utilities Commission (PUC) General Order 58-A, "Standards for Gas Service in the State of California," last revised April 1989

- Individual public utility's contract agreement.

The PUC General Order 58-A and the utilities' contract agreements apply to the safe transport of gas through the pipeline systems. The commercial gas quality standards specified include general limits on such parameters as flammability, water content and other corrosion precursors, energy content, and gas delivery pressure. No restrictions on compositional elements such as methane, ethane, propane and other heavier hydrocarbons are specified.

The commercial LPG standard is the voluntary industry standard for "commercial propane", which allows up to 50 percent propene content. Table III-3 shows the compositional elements of the commercial propane standard.

Table III-3: Commercial Standard for LPG

Constituent	*Commercial Propane*
Propane	"predominantly propane"
C_4+ (butane & heavier)	< 2.5%
Olefins (e.g., propene)	(no limit)

F. Alternative Fuels Enforcement

Enforcement of the alternative fuels regulations is similar to enforcement of the gasoline and diesel regulations within California. The proposed amendments will not change the enforcement procedure. ARB staff will test the fuel at fueling stations, to determine compliance. If the fuel is being used to fuel motor vehicles and does not comply with the motor vehicle specifications, ARB staff will consider all of the parties that are responsible for supplying the fuel to be in violation of the alternative fuels regulations. However, chemical analysis speciation data for the fuel at locations in the distribution system upstream of the fueling facility will be considered in assessing liability.

IV. Description and Rationale of the Proposed CNG Amendments

A. Proposed Amendments

Staff is proposing to establish new CNG specifications based on methane number (MN) to provide more flexibility for producers and suppliers of CNG to comply with the specifications. These specifications will be an additional compliance option to the existing specifications. Specifically, staff proposes two additional specifications: a statewide specification of MN 80, and an alternative specification of MN 73 available in the SSJV and SCC to fleet operations that meet the following criteria:

- The natural gas service provider does not provide natural gas that meets an MN of 80 at the service connection;
- The vehicles fueled at the facility are recommended by the engine manufacturer as being able of operating on CNG with a MN of 73; and
- The fueling station has controls in place that will prevent misfueling.

Staff also proposes two definitions that are necessary to define the SSJV and SCC. For the purpose of these specifications, SSJV will be defined as inclusion of the following counties within the jurisdiction of the San Joaquin Valley Air Pollution Control District: Fresno, Kings, Tulare, and Kern counties. The SCC includes San Luis Obispo and Santa Barbara counties.

B. Rationale

1. Feasibility of Meeting the Proposed Alternative Specifications

Staff is proposing amendments to the alternative fuels regulations for CNG to increase compliance flexibility and the availability of complying CNG in California. There are areas in California where the availability of CNG meeting the motor vehicle fuel specifications is very limited. These areas include the SSJV and the SCC where natural gas is produced in association with oil production. This gas or "associated gas" typically does not meet the motor vehicle fuel specifications for CNG. But because this gas meets the commercial quality specifications for natural gas, it is allowed to enter the common pipeline that supplies natural gas to residential, commercial, industrial, and motor vehicle end-users. Therefore, SSJV and SCC gas that is drawn off the pipeline in these areas for motor vehicle CNG use may exceed the CNG motor vehicle specifications and would be considered a non-compliant fuel.

Methane number (MN) for CNG is similar to the octane number used in gasoline. Like octane number, MN provides an indication of the knock tendency of the fuel. MN can be calculated from the fuel composition as demonstrated in Appendix D. The primary benefit from using MN is the flexibility it provides in allowing the CNG composition to vary. A producer can improve gas quality by choosing which fuel components to reduce or remove. The heavier or higher carbon chain components are easier to remove and have a greater adverse influence on the MN than the lighter components. Thereby a reduction of the heavier components will have a larger positive impact on the MN (improvement in gas quality) than the lighter components.

Based on this, staff has determined that alternative CNG specifications using the methane number index would provide more compliance flexibility with the regulations. By providing additional compliance options, the proposed amendments allow gas suppliers to tailor modifications to their facilities, which will enable them to comply with the specifications easier; thereby, increasing the availability of motor vehicle grade fuel.

2. Performance

The proposed MN 80 will not cause performance or durability concerns with existing and new technology engines. Existing engines (open-loop and first generation closed-loop technology) were designed to handle the existing CNG motor vehicle fuel specifications (about MN 80 to 82). Engine manufacturers agree that these existing engine technologies can properly operate on CNG with a methane number of at least 80. Also, major engine manufacturers agree that the newer advanced technology engines can operate on a broader range of fuel quality. These engines can properly operate on CNG with a methane number as low as 73.

3. Supply

The proposed amendments would increase the amount of fuel available for use as motor vehicle fuel by providing more flexibility to comply with the regulations. Currently, 89 percent of the statewide supply of CNG is in compliance with the existing motor vehicle fuel specifications. The proposed MN 80 specification would increase this amount to about 91 percent by increasing the amount of CNG that would comply in the SSJV and SCC.[9]

In the SSJV and the SCC where most associated gas production occurs, almost all of the CNG supply in these regions does not comply with the existing motor vehicle fuel specification. The proposed MN 73 specification would increase the local supply of complying CNG to about 88 percent in the SCC and 99 percent in SSJV.[9] In this area, only a relatively small number of current technology vehicles exist using about seven fueling facilities. Since future growth in CNG vehicles will be new technology vehicles, it is feasible for these regions to accommodate an MN 73 CNG specification.

In the Los Angeles Basin, no impact on CNG supply is expected to occur since essentially all of the gas used for motor vehicles use comes from clean imported sources. Also, since this region has a significant amount of existing technology vehicles that require a MN 80 fuel, staff is not recommending the allowance of a MN 73 fuel.

4. Emissions

The proposed amendments would have no significant adverse impact on mass emissions from CNG vehicles. The proposed MN 80 specification is very similar to the existing CNG motor vehicle fuel specifications. Test data on light and heavy-duty engines using MN 80 CNG shows no impact on emissions from fuel meeting the current CNG motor vehicle fuel specifications. Regarding the proposed MN 73 specification, test data on light-duty vehicles shows only minimal effects on emissions, both increases and decreases, as summarized in Table IV-1[5]. For advanced technology closed loop heavy-duty vehicles, test data shows no discernable impact on PM and NOx emissions and only a slight impact on CO_2 and NMHC emissions (as summarized in

Table IV-2[10]). A complete discussion on the fuel effects on emissions is discussed in Chapter VII and Appendix B.

Table IV-1: Range of emissions by pollutant for MN 89 and MN 63 CNG for Light-Duty Dedicated NGVs

Pollutant	MN 89 CNG (g/mi)	MN 63 CNG (g/mi)
CO	0.46 – 1.26	0.29 – 1.48
NOx	0.09 – 0.17	0.05 – 0.20
NMOG	0.016 – 0.027	0.012 – 0.030

Table IV-2: Range of emissions by pollutant for MN 80 and MN 73 CNG for Advanced Technology Heavy-Duty NGVs

Pollutant	MN 80 CNG (g/mi)	MN 73 CNG (g/mi)
CO	0.2 – 4.2	0.2 – 4.2
PM	0.009 – 0.029	0.008 – 0.031
THC	7.5 – 7.9	7.5 – 8.2
NOx	6.9 – 12.8	6.1 – 11.0
NMHC	1.3 – 2.7	1.5 – 3.0
CO_2	944 – 1020	978 – 1077

The proposed amendments will help to ensure the continued emission benefits of CNG fueled vehicles. As discussed in Chapter VII, typical in-use diesel PM emissions from buses without after-treatment represent a three- to five-fold increase over typical PM emissions from CNG buses using compliant motor vehicle fuel. On average, NOx emissions from diesel buses are greater than NOx emissions from CNG buses.[7]

C. Future CNG motor vehicles fuel specifications

The proposed amendments provide increased compliance flexibility that will increase the availability of motor vehicle grade CNG. This will facilitate the continued use of the existing CNG fleets, maintain the emissions benefits of CNG vehicles, and improve the expansion of the

CNG market. However, to address the need for future emission control strategies to meet the federal and State ambient air quality standards, it may be necessary in the future to re-evaluate the CNG motor vehicle fuel specifications. Specifically, future motor vehicle exhaust emissions standards may require the cleanest fuels available. Therefore, CNG as well as other alternative fuels may need to be further refined to accommodate future engine technologies and vehicle exhaust emission standards. The MN 73 specification may be temporary.

V. Description and Rationale of the Proposed LPG Amendments

A. Proposed Amendments

Staff is proposing to add a provision allowing small local delivery trucks, which deliver LPG fuel to non-motor vehicle accounts an exemption from the LPG motor vehicle specifications. Small local delivery trucks or "bobtails" are defined as a truck capable of being fueled off of the cargo tank with a maximum capacity of 3000 gallons. These vehicles would be allowed to operate on commercial grade LPG.

B. Rationale

1. Performance

Bobtail trucks transport fuel to non-motor vehicle and motor vehicle accounts. Although some bobtail trucks have a side-saddle fueling tank, many do not, and they fuel on the same cargo fuel that they are delivering. These trucks have operated intermittently on off-specification fuel for the last ten years. Although engine manufacturers believe that additional maintenance is necessary to maintain engine performance and fuel economy, only a few fleet owners have indicated that additional maintenance is necessary. According to the suppliers, marketers and fleet owners of bobtail trucks, the trucks have not had any durability or engine performance problems over the last ten years. In addition, vehicle testing demonstrates that engine performance was unaffected by fuel blends, and no abnormal wear to the engine was detected. Additional detail on the testing programs is discussed in Chapter VIII and Appendix C.

2. Supply

These proposed amendments will not affect the supply of motor vehicle grade LPG.

3. Emissions

When comparing emissions from heavy-duty vehicles operating on the current motor vehicle specification LPG to commercial grade LPG fuel, NMHC emissions decrease by 11 percent, CO emissions decrease by 20 percent, and NOx increase by 14 percent. However, the NOx emissions increase is still within the original vehicle emission certification standards, since these vehicles were originally certified on diesel.

When compared to diesel, vehicles operating on commercial LPG have significantly less PM emissions. If bobtails were to convert back to diesel, PM emissions could potentially increase above existing levels. To prevent this from occurring, we believe it is necessary to include this exemption. Additional information can be found in Chapter IX and Appendix C.

VI. Discussion of Compressed Natural Gas as a Motor Vehicle Fuel

A. Overview of CNG as a Motor Vehicle Fuel

Compressed natural gas (CNG) is a highly compressed form of the natural gas. Natural gas is a combustible, gaseous mixture primarily composed of methane (CH_4), with small amounts of ethane (CH_6), propane (C_3H_8), butane (C_4H_{10}) and pentane (C_5H_{12}). Natural gas is produced either from gas wells which do not produce any crude oil (non-associated gas) or in conjunction with crude oil production (associated gas). In California, associated gas is produced within the southern half of the state.

In California, natural gas is distributed in an extensive pipeline system that extends from the well-head to the end user. The pipeline system consists of long-distance transmission lines, operating at 250 to 1,000 pounds per square inch gauge (psig) pressure, which transfer natural gas from a gathering line (production facility) or storage facility to a distribution center or another storage facility. From there, natural gas is distributed by local distribution lines to customers through either a 60-psig high-pressure distribution system or a low-pressure system that delivers natural gas to a residential gas meter at 1/4 psig.

The natural gas pipeline also serves as the source for CNG. At strategically located CNG fueling outlets, natural gas is pulled off the pipeline and is compressed to 3,000 to 3,600 psig for motor vehicle use.

CNG fueling outlets are provided by natural gas utilities and through a limited number of major gasoline retailers and independent CNG retailers. In California, the utilities include the City of Long Beach Gas Department, Pacific Gas and Electric (PG&E), San Diego Gas & Electric, and SoCalGas. These companies do not produce or own the gas but are the service providers that own and maintain the pipeline infrastructure that delivers the gas.

As of July 2001, there are 212 CNG fueling sites in existence throughout California. More than half of these compressor stations have full or limited access to the public, providing both "time-fill" (slow-fill requiring two to three hours to refuel) and "fast-fill" (quick-fill requiring two to five minutes) systems. In addition, individual home compressors are also available which use a time-fill system for overnight refueling. A small compressor is usually located in a home's garage area and connected directly to the natural gas supply to the house.[11]

B. Current Gas Quality Issues

In 1999, about 16 percent of the natural gas used in California was produced in the State and 84 percent was imported from the Rockies and the southwestern United States, and Canada. The natural gas imported into California generally meets the existing specifications for CNG motor vehicle fuel. Of the 16 percent of the natural gas produced in California, about 72 percent is associated gas (gas produced in association with oil production) which can vary widely in properties.[12] Generally, the ethane content and the propane and heavier hydrocarbons content (referred to as C3+) of associated gas can often exceed the levels in the CNG motor vehicle fuel specifications but meet the pipeline specifications for commercial natural gas. The remaining 28 percent of total California production of natural gas is non-associated gas (gas produced from gas wells which do not produce any crude oil) which is high in methane content and normally meets the existing motor vehicle CNG specifications.

As discussed previously, natural gas produced in Northern California is non-associated gas. In addition, natural gas supplied to Northern California is imported gas from out-of-state. Thus, fuel quality is not an issue in Northern California.

Production of associated gas is concentrated in the SSJV and SCC region. Generally, the associated gas in the SSJV tends to have a greater ethane content than the specifications for CNG motor vehicle fuel. The associated gas in the SCC almost meets the ethane content, but it exceeds the C3+ content. Table VI-1 compares the CNG motor vehicle fuel specifications to the pipeline gas in the SSJV and SCC.

Table VI-1: Comparison of Existing CNG Motor Vehicle Fuel Specifications to Pipeline Gas in Southern San Joaquin Valley (SSJV) and South Central Coast (SCC)

Component	*SSJV Pipeline Gas*		*SCC Pipeline Gas*		*Motor Vehicle Specifications*
	Average	*Range*	*Average*	*Range*	
Methane (mole%)	86.0	79-97	88.5	86-97	88.0 min.
Ethane (mole%)	8.9	0-12	5.2	0-8	6.0 max.
C3+ (mole%)	2.7	0-9	3.8	0-6	3.0 max.
Inerts (mole%)	2.4		2.5		4.5 max.
CO_2	1.9	2-3	2.0	2-3	
N2	0.5	0-1	0.5	0-1	
BTU	1100	990-1181	1095	990-1141	N/A

As can be seen in Table VI-1, there is a significant variation in natural gas quality in both regions. The volume-weighted average for the SJV region is about 9 mole percent ethane with the ethane content varying significantly from almost none to as high as 12 mole percent. The volume-weighted average for the SCC region is 3.8 mole percent C3+ with the C3+ varying from almost none to as high as 6 mole percent.[13]

Historically, producers have not processed or treated their natural gas to meet the CNG motor vehicle specifications. In California a market does not exist for ethane. As a result, most gas plants are not equipped for or designed to extract ethane. In other parts of the country, ethane is extracted from natural gas because it is marketed for use in the petrochemical industry. In

California, the only likely use for ethane is as an onsite fuel but many facilities may not have enough demand to absorb all of the ethane that would be extracted.

In contrast, a market does exist for propane in California. However, the demand for propane is seasonal (i.e., high in the winter for home heating - see LPG section for further discussion). As discussed in the previous section, heavier hydrocarbons that naturally accompany associated gas as it leaves the ground include ethane, propane (LPG), butane, and pentane. Because propane boils at -44 degrees Fahrenheit and ethane boils at -127 degrees Fahrenheit, less processing is needed to separate propane than ethane. Generally, the heavy gases are removed from the raw natural gas stream, leaving mostly methane before entering the natural gas pipeline distribution system. The removal of the heavy gases is refers to as liquid extraction or liquid recovery. Producers in SSJV and SCC do have limited capacity to extract propane and heavier hydrocarbons from the natural gas. However, additional propane extraction or recovery has economic tradeoffs. Producers will run their systems to maximize propane recovery if the liquid sale can make up the operational cost.[14]

As noted above, the ethane content in the SJV region and the C3+ content in SCC region exceed the levels allowed by the CNG motor vehicle fuel specifications. Because associated gas is regionally produced, most of this gas is consumed locally with no opportunity to be diluted with higher quality gas in the pipeline. Thus, gas that is drawn off the pipeline in these areas for motor vehicle CNG use typically does not meet the CNG specifications. Currently, SoCalGas, the main service provider for Southern California, is blending the pipeline gas with high quality gas that is trucked to various NGV fueling stations in the affected regions to ensure that the CNG supplied to motor vehicles meets the motor vehicle CNG specifications. However, SoCalGas's ability to manage the fueling stations is limited by the blending gas transport vehicle and the local restrictions on pick-up and delivery at the blend gas production site.

The current gas quality issues in these regions have prevented the expansion of additional CNG re-fueling stations. Presently, there are about twenty (20) businesses that have applied to the utilities for the installation of CNG re-fueling stations. These requests have been put on hold because the utilities are not certain that they will be able to provide the stations with motor vehicle grade CNG.

During the recent energy crisis in California, there has been an increase in natural gas production in the San Joaquin Valley. Also, changes in supplier contracts have resulted in decreased demand in the region. These events have resulted in an increase in migration of SJV produced associated gas to the Los Angeles basin. As discussed, this gas meets the pipeline quality standards, but does not comply with the motor vehicle specifications for CNG. The increased migration of this gas could potentially affect CNG fueling sites in the Los Angeles basin.

C. Engine Performance Issues

If allowed to be used in vehicles without treatment or blending to meet minimum specifications, the variation in CNG composition seen throughout the SCC and SSJV can adversely affect engine performance. These effects can include misfire, stumble and underrated operation[15] as well as engine knock and overheating that can lead to possible catastrophic failure. Light-duty engines are less susceptible to these fuel-related performance problems because of the engine operation controls that have been developed for emissions control. Recent advances in engine controls for heavy-duty engines have resulted in newer heavy-duty engines that are more tolerant of variable fuel quality. However, there is a wide range of heavy-duty CNG engine technologies currently in use in California. The older or less sophisticated heavy duty CNG engine technologies are susceptible to fuel-related performance problems. This vehicle population must be either safeguarded against these problems by ensuring that the engines operate on a minimum quality fuel or replacing the engines with more advanced engine technology.

D. Gas Quality Indices

Two measures of CNG gas quality are the Wobbe Index and the methane number. The Wobbe Index is a measure of the fuel interchangeability with respect to its energy content and metered air/fuel ratio.[16, 17] Thus, changes in Wobbe Index can affect the engine's metered air/fuel ratio and power output.[18] The Wobbe Index is calculated from the energy content of gas (using the higher heating value of the energy content range), and the relative density of the gas. The relative density of the gas is the ratio of the gas density to the density of air.

Wobbe Index = Higher Heating value / (relative density)

The methane number is a measure of the knock resistance of the fuel. Knock, or detonation, can be extremely damaging to an engine. Knock occurs when there is uncontrolled combustion with multiple flame fronts rather than smooth combustion proceeding along a flame front initiated at the spark plug.[19, 20] Knock can result from the heat produced by compression of the air/fuel gas mixture in the piston. The knock resistance of the fuel is a function of the fuel composition. Methane has a very high knock resistance. The heavier hydrocarbons in CNG, such as ethane, propane, and butane, have lower knock resistance and thus reduce the overall knock resistance of the fuel. Methane number and how it is determined in explained in Appendix D. The current CNG motor vehicle fuel specifications equate to a methane number of approximately 80 to 82, depending on the speciation of the C3+ content, as shown in Appendix D.

VII. CNG Engine Types and Fuel Quality Requirements

A. Light-Duty Engines

Light-duty engines are stoichiometric burn engines with three-way catalyst exhaust after-treatment and exhaust feedback control developed to meet light-duty vehicle exhaust emissions standards.[21] Stoichiometric burn engines are designed for an air/fuel ratio that can completely burn the fuel without excess air. Light-duty engines have feedback controls that process information from the exhaust to aid in engine operation. Engines with feedback controls are called closed loop systems. Both the feedback controls used for light-duty engines and their stoichiometric operation make them very tolerant of the natural gas fuel variations seen in California. A survey of light duty vehicle manufacturers indicated that fuel quality requirements for light duty engines are more frequently cited in terms of Wobbe Index. Manufacturer recommended gas quality requirements range approximately from a minimum of 1300 BTU/ft3 to a maximum of 1400 to 1500 BTU/ft3.[18,22] These equate to a minimum methane number of approximately 65 to 70, as discussed in Appendix E.

A test program to determine the effect of fuel quality on emissions and driveability for light-duty vehicles was sponsored by the Gas Research Institute (GRI), Pacific Gas & Electric (PG&E), SoCalGas, Atlanta Gas Light Company (AGL), automakers, and regulatory agencies. This test program is discussed in Appendix B. The test program used eight light-duty natural gas vehicles (NGV) with five different fuel qualities. The tested fuel qualities ranged from a methane number of approximately 65 to 100. Test results showed that for original equipment manufacturer (OEM) dedicated NGVs, even large variations in fuel composition produced only slight variations in the emissions and driveability, both increases and decreases, while bifuel vehicles had only modest changes in emissions and performance.[5,6] This is shown by a comparison of the measured emissions ranges obtained with the MN 89 gas and a MN 63 minimum quality gas given in Table VII-1 below for the OEM dedicated NGVs.

Table VII-1: Range of emissions for MN 89 and MN 63 CNG for OEM Dedicated NGVs

Pollutant	MN 89 CNG (g/mi)	MN 63 CNG (g/mi)
CO	0.46 – 1.26	0.29 – 1.48
NOx	0.09 – 0.17	0.05 – 0.20
NMOG	0.016 – 0.027	0.012 – 0.030

B. Medium-Duty and Heavy-Duty Engines

Medium-duty and heavy-duty engines are usually designed as lean-burn engines because these engines are more fuel-efficient and produce lower combustion temperatures than stoichiometric burn combustion. Lean-burn engines are designed to operate at an air/fuel ratio with more air than required to completely burn the fuel. This engine technology has been used to meet applicable exhaust emission standards without the use of after-treatment technology. However, as explained in Appendix E, lean-burn engines are more susceptible to problems associated with variable gas quality.

Early CNG lean-burn engines operated without feedback controls. Theses are called open loop systems. Open loop lean-burn engine technology is the least tolerant of variable gas quality. Most CNG lean-burn engines currently being manufactured include closed loop engine technology. Recent advances in lean-burn engine feedback control have made some closed loop heavy-duty engines more tolerant of variable fuel quality than others. The less tolerant closed loop engines will be referred to as first generation closed loop engine technology. Open loop and first generation closed loop engine technologies require fuel with a methane number of 80 or higher. The more advanced engine technology will be referred to as "advanced generation closed loop" engine technology. Advanced generation closed loop engine technologies can tolerate a fuel quality with a methane number as low as 73. Advanced generation engine technology is being successfully used in a number of SSJV and SCC fleets operating on fuel that does not meet the current CNG motor vehicle fuel specifications where a test program exemption has been granted by the ARB. Additionally, there are closed loop engines recently certified by ARB as low emissions engines that can tolerate methane numbers as low as 65.[23] The different engine technologies, i.e. stoichiometric versus lean-burn and open versus closed loop, are explained in more detail in Appendix E.

A test program was sponsored by the Gas Research Institute (GRI), Pacific Gas & Electric (PG&E), SoCalGas, Atlanta Gas Light Company (AGL), automakers, and regulatory agencies to determine the effect of fuel quality on emissions and performance for seven different heavy-duty open and closed loop engine technologies.[10] The results of this testing are summarized in Appendix B. The tested CNG qualities ranged from MN 73 to MN 99. These data showed that fueling advanced generation engine technologies with MN 73 fuel produced no discernible impact on the PM and NOx emissions when compared to measured emissions of the other cleaner fuels, as shown below in Figure VII-1 and Figure VII-2, respectively.

Figure VII-1: Measured PM Emissions versus Methane Number for Advanced Generation Closed Loop Engines

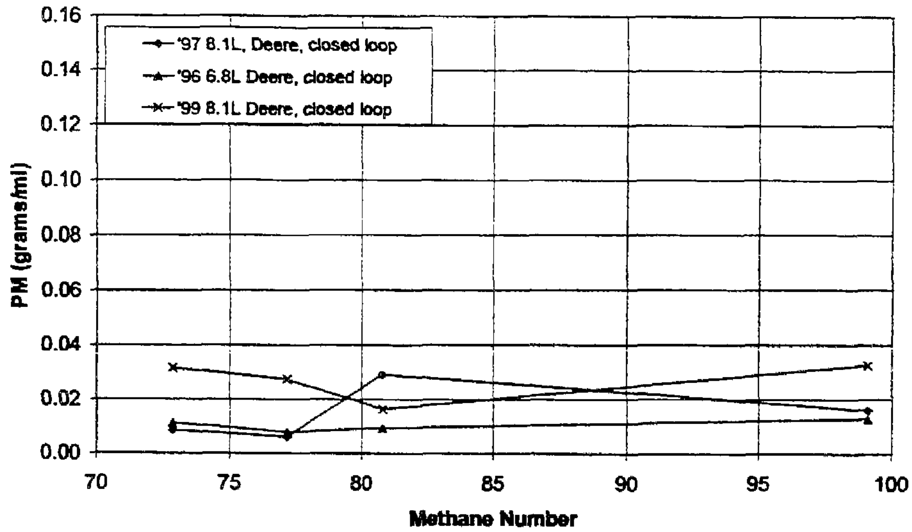
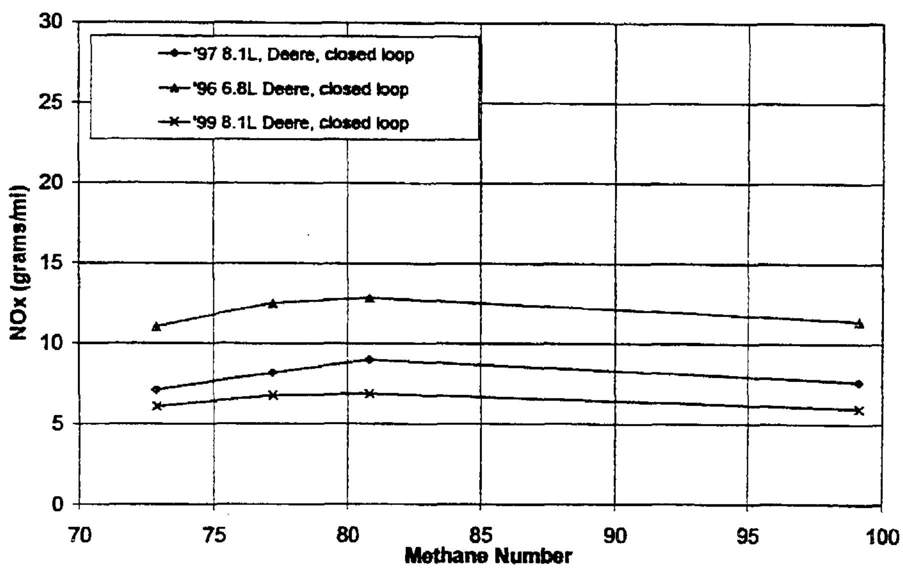


Figure VII-2: Measured NOx Emissions versus Methane Number for Advanced Generation Closed Loop Engines



The measured emissions ranges for the advanced generation closed loop vehicles are summarized in Table VII-2 below for a fuel equivalent in methane number to the current specifications, MN 81, and for a MN 73 fuel. As shown, there were increases in carbon dioxide (CO_2) and nonmethane hydrocarbon (NMHC) emissions of about six percent and approximately 10 percent respectively. There were no discernible impacts on the other emissions.

Table VII-2: Range of emissions for MN 81 and MN 73 CNG for the Tested Advanced Generation Closed Loop Vehicles

Pollutant	MN 81 CNG (g/mi)	MN 73 CNG (g/mi)
CO	0.2 – 4.2	0.2 – 4.2
PM	0.009 – 0.029	0.008 – 0.031
THC	7.5 – 7.9	7.5 – 8.2
NOx	6.9 – 12.8	6.1 – 11.0
NMHC	1.3 – 2.7	1.5 – 3.0
CO_2	944 – 1020	978 – 1077

C. Industry's Efforts to Address CNG Issues

Currently, industry is considering a combination of market options to address the issues related to off-specification CNG. Options include increased gas processing, continued pipeline blending, and engine re-powering.

Improvements in gas processing at major production sites in the SSJV and the SCC are being considered by the industry. Improvements range from moderate gas plant modifications to installing new gas plant capacity. These improvements would allow major gas producers to meet or exceed a gas quality of MN 80. By significantly improving the gas quality for most of the gas produced in these regions, it may be possible to maintain the average pipeline quality above MN 80.

Pipeline blending is another option that has been used in the past and can be used to provide added assurance that pipeline gas quality is maintained. Specifically, the gas that is sent down to the Los Angeles basin must meet a MN 80 to protect the existing CNG motor vehicle fleet. SoCalGas has indicated that it can monitor the quality of gas at a strategic location on the pipeline and, if necessary, blend in high quality gas to improve the quality of the gas that is sent to the LA Basin. However, blending will displace an equivalent amount of gas and would likely involve some curtailment in the amount of gas that is allowed to enter the pipeline from the producers in the SSJV and the SCC. SoCalGas is presently discussing the possibility of gas curtailments with gas producers if significant pipeline blending occurs.

Re-powering existing engines in SSJV and the SCC is an option that would facilitate the use of MN 73 CNG in these regions. As discussed, light-duty vehicles and advanced closed-looped technology heavy-duty vehicles can properly operate on MN 73 CNG. However, existing open-looped and first generation closed-looped technology heavy-duty vehicles require MN 80 CNG. Therefore, re-powering these vehicles with advanced closed-looped technology would allow the use of MN 73 CNG in these regions.

To facilitate these industry options, the proposed amendments to the CNG motor vehicle fuel specifications would allow the use of a flexible fuel specification based on methane number. The proposed amendments would also allow the option of an alternative MN 73 specification for vehicles that operate in the SSJV and the SCC.

For future CNG fueling sites, industry will need to consider the quality of the fuel that is available. Generally, while the vast majority of potential sites will not have any fuel quality issues, potential fleet operators should coordinate with their gas provider to determine the quality of fuel that is available. Staff has identified small pockets of gas production in the Los Angeles Basin that do not meet the MN 80 specification. This gas production does not currently affect existing CNG fueling stations, but can potentially impact future fueling stations if located in the close proximity of these pockets. Thus, potential fleet operators in coordination with the gas provider should consider the quality of gas available in selecting future fueling sites.

For the region where the MN 73 option is allowed, potential fleet operators should coordinate with their gas service provider to determine the quality of fuel that is available and the appropriate technology vehicles that can be fueled with the fuel.

VIII. Discussion of Liquefied Petroleum Gas as a Motor Vehicle Fuel

A. Overview of LPG as a Motor Vehicle Fuel

LPG refers to a mixture of light hydrocarbons, predominantly propane, that is pressurized into a liquid for use as a fuel. LPG has uses similar to those of natural gas. In addition to its application as a motor vehicle fuel, LPG is used in space heating (e.g., in rural buildings and recreational vehicles) and portable appliances (e.g., barbecues), as well as heating and cooking in areas where natural gas is not available.

LPG is produced and supplied from oil refineries and by gas plants in oil and gas fields. In refineries, it is a by-product of processes that produce gasoline. At gas plants, LPG is separated from crude oil and from natural gas.

LPG from refineries can contain substantial amounts of propene. The propene content in LPG is partly dependent on a refiner's use of fluidized catalytic cracking units (FCC), or coking units. These processing units create olefin compounds (such as propene) in its by-product gas that largely makes up LPG. However, the actual propene content in LPG will depend on whether or not a refinery separates the olefins from the by-product gas for use in processes that make high-octane gasoline blending materials such as alkylates. Without such processes, a refiner has no in-house use for propene. Thus, it is generally more economical for a refiner to blend the propene-rich by-product gas into its LPG product stream.

LPG from gas plants has almost no propene if the LPG comes only from production fields. However, some gas plants also receive by-product gas from refineries. LPG from such gas plants can contain substantial propene.

In California, about 90 percent of the total LPG production comes from oil refineries and 10 percent comes from gas plants in oil and gas fields. California imports roughly 25 percent from other states and Canada during the winter months (generally November through March) when demand is high and exports about the same amount to other states and other countries during the summer (generally April through October) when demand is slow. The LPG imported into California generally is of motor vehicle LPG quality (10 or less volume percent propene content).[24] California produces two grades of LPG, motor vehicle and commercial (greater than 10 volume percent propene content).

In Central California and Southern California mainly motor vehicle grade LPG is produced, while in Northern California two grades of LPG are produced. Most gas plants are concentrated in Central California, near oil producing sites. Thus, this LPG contains little or no propene and meets the motor vehicle specifications for LPG. Southern California refineries are configured such that the LPG produced is typically less than 10 volume percent propene content. In Northern California, the refineries, with one major exception, were not configured to maximize capture of light olefins for processing in alkylation units. As a result, one refiner produces motor vehicle grade LPG and two do not. Two other refineries are not selling LPG.

LPG storage is generally separated into three categories. The first is primary storage at refineries, gas plants, and pipeline tanks. Also used are large bulk storage facilities built from depleted underground mines and salt domes, which are clustered mostly around Conway, Kansas; Hattiesburg, Mississippi; and Mont Belvieu, Texas. In California, primary storage exists at one bulk terminal with above ground tanks, and at refineries and gas plants. Secondary storage consists of above-ground tanks located at distribution centers, retail outlets, and satellite locations. The third type of storage is tertiary storage, consisting of tanks at point of end-use which are primarily at residences, businesses, and farms. During the summer months (generally April through October) when demand is slow, LPG marketers make a concerted effort to ensure that their tanks, secondary storage, are full and that their customers' tanks, tertiary storage, are also full to meet wintertime demand.[25]

In California, LPG is transported by trucks and railroad tank cars. Typically, LPG is transported by bulk transport trucks (maximum capacity of 10,000 gallons) and railroad tank cars (maximum capacity of 30,000 gallons per tank car) from the refineries and gas plants to the distribution centers and retail outlets. Smaller local delivery trucks (maximum capacity of 3000 gallons), commonly referred to as "bobtails," transport the LPG from these locations to the final customers. Most of these bobtails have the capability to fuel on the LPG that is contained in the cargo tank.

LPG is typically distributed in one of three ways:

1) A distributor/marketer picks up the LPG by bulk transport truck or railroad tank cars from a producer's loading rack and delivers it in bulk to its own regional storage facility, or directly to a customer's storage tank.

2) A distributor/marketer picks up the fuel from a bulk terminal (e.g. Suburban Elk Grove Terminal) or a regional storage facility and delivers it directly to its customers' sites, or stores it in its own storage tank, from which bobtails are used for subsequent deliveries.

3) End use customers bring their LPG portable containers or vehicles for filling at retail or wholesale facilities.

Most LPG is delivered to end users from the marketers' own storage tanks. Most marketers have only one tank and one dispensing system for LPG.

B. LPG Bobtail Delivery Truck Issues

A bobtail delivery truck is a LPG transport truck capable of transporting up to 3000 gallons of LPG. A bobtail is used to make local deliveries from the LPG distribution centers and retail outlets directly to the final customers of both non-motor vehicle and motor vehicle accounts.

Most bobtails fuel on the LPG that is contained in the cargo tank. Therefore, if the cargo fuel is for a commercial account, bobtails operating in Northern California could be running on off-specifications LPG. Although some bobtails are equipped with a side-saddle fueling tank which is independent of the cargo tank, it is neither practical nor economical for the operator to secure motor vehicle LPG, especially in areas where non-motor vehicle accounts exist.

The WPGA reported less than 1000 bobtails operating in the State with about 500 operating in Northern California. According to the suppliers and marketers of commercial propane, bobtail trucks have routinely fueled on commercial LPG for the last ten years. Some increased maintenance and services are typical of these trucks; however, there have been no reports of any durability or engine performance problems in bobtail trucks over this time frame.[8]

C. Summary of Emissions, Performance, and Durability Testing

Studies have been conducted to evaluate emissions, engine performance, and engine durability associated with different formulations of LPG. Three emissions studies include the LPG Task Group test program, the WPGA test program, and the ARCO tests. The LPG Task Group test program is the 1998 test program coordinated by staff with a LPG Task Group established by the ARB to oversee the project. The task group consisted of representatives from refiners, engine makers, automakers, LPG marketers, and government agencies. The LPG Task Group test program also evaluated engine performance and engine durability. Detroit Diesel Company also conducted engine performance testing. Appendix C provides a detail discussion of the emissions, performance, and durability studies.

To estimate the emissions effects of bobtails operating on commercial grade LPG, staff used the LPG Task Group emissions data, which evaluated heavy-duty engine on varying propene content as high as 21 percent. Table VIII-1 summarizes the potential effects of two LPG blends with propene content greater than 10 volume percent in relation to a 10 volume percent propene LPG fuel on a Cummins B5.9 medium heavy-duty LPG engine.

Table VIII-1: Estimates of Emission Effects in LPG Heavy Duty Vehicles[a]

Greater than 10% Propene vs. 10% Propene[b]

Fuel	*NMHC or THC*	*NOx*	*CO*
	(percent change)		
1 (14.6% propene,5.0% butane)	-5%	3%	20%
2 (21.3% propene,1.6% butane)	-11%	14%	-20%

[a]Cummins B5.9 medium heavy-duty LPG engine.

[b]LPG fuel at 9.8 volume percent propene, 5.0 volume percent butane.

As shown from the table, increasing the propene content (fuel 1) appeared to decrease hydrocarbon emissions (NMHC or THC), but increase oxides of nitrogen (NOx); and carbon monoxide (CO) emission. However, increasing the propene content and reducing the butane content to less than 2.5 percent (fuel 2), as specified in the commercial LPG standard, appeared to only increase NOx emissions. As seen from the table, the NOx emission increases could be as high as 14 percent more than a 10 volume percent propene LPG fuel.

The LPG Task Group test program also evaluated engine performance and engine durability associated with different formulations of LPG on a Cummins B5.9-195 LPG engine. Detroit Diesel Company reported results on engine performance testing of a Detroit Diesel Series 50 engine. Both the Task Group and the Detroit Diesel studies reported testing only different LPG formulations up to 10 volume percent propene. The Task Group results show that for up to 10 volume percent propene content engine performance was unaffected by LPG blends, and no abnormal wear to the engine was detected. The Detroit Diesel results show that performance is well within the design of the vehicle.

IX. Environmental Impacts of the Proposed Amendments

This section discusses the environmental impact of the proposed amendments to the CNG motor vehicle fuel specifications and the LPG motor vehicle fuel specifications.

A. Overview of Environmental Impact Analysis

The staff evaluated the environmental impacts of the proposed amendments and determined that the amendments would have no significant adverse impact on public health or the environment. As discussed in Chapter IV, the proposed amendments for CNG provide an alternative set of specifications in addition to the existing CNG specifications. The proposed amendments for LPG do not change the current LPG fuel specifications but provide an exemption for specific delivery vehicles from the fuel specifications.

The staff evaluated the environmental impacts of the proposed amendments following the requirements of the California Environmental Quality Act and the Public Resources Code section 21159. The staff also followed the requirements of Health and Safety Code 43830.8, which requires the state board to conduct a multi-media evaluation before adopting any regulation that establishes a specification for motor vehicle fuels. The following discusses the specific requirements of these statutes and staff's environmental impact analysis.

B. Environmental Requirements

The California Environmental Quality Act (CEQA) and ARB policy require an analysis to determine the potential adverse environmental impacts of the proposed standards. Because the ARB's program involving the adoption of regulations has been approved by the Secretary of Resources (see Public Resources Code, section 21080.5), the CEQA environmental analysis requirements are to be included in the ARB's Staff Report in lieu of preparing an environmental impact report or negative declaration. In addition, the ARB responds in writing to all significant environmental issues raised by the public during the public review period or the public Board hearing. These responses are to be contained within the Final Statement of Reasons for the proposed amendments.

Public Resources Code section 21159 requires that the environmental impact analysis conducted by the ARB include the following: 1) an analysis of the reasonably forseeable environmental impacts of the methods of compliance, 2) an analysis of reasonably forseeable mitigation measures, and 3) an analysis of reasonably foreseeable alternative means of compliance with the standard. Our analyses of the reasonably foreseeable environmental impacts of the methods of compliance are contained in the environmental impact analysis. Because the proposed amendments do not result in any significant environmental impact, mitigation measures are not necessary. In regards to reasonably foreseeable alternative means of compliance, the proposed amendments add alternative fuel specifications; therefore, the existing fuel specifications can still be used for compliance.

Health and Safety Code section 43830.8 requires the state board to conduct a multimedia evaluation before adopting any regulation that establishes a specification for motor vehicle fuel. Section 43830.8 defines "multimedia evaluation" as "the identification and evaluation of any significant adverse impact on public health or the environment, including air, water, or soil, that may result from the production, use, or disposal of the motor vehicle fuel that may be used to meet the state board's motor vehicle fuel specifications." Section 43830.8 also requires the California Environmental Policy Council (CEPC) to review the multimedia evaluation and determine if any significant adverse impact on public health or the environment may result from a proposed regulation. Section 43830.8 also allows the CEPC to determine, through an initial evaluation, that no multimedia evaluation is required based on its finding that a proposed regulation has no significant adverse impact on public health and the environment.

Because staff has determined that the proposed amendments will not have any significant adverse impact on public health or the environment, staff has made a formal request to the CEPC to exempt this regulatory proposal from CEPC review and the need for a multimedia evaluation. The exemption request is currently under review by the CEPC.

Below presents staff's impact analysis of the potential environmental impacts of the proposed amendments.

C. Environmental Impact Analysis

1. Effects on Water Quality and Waste Disposal

The proposed amendments to the CNG and LPG specifications do not change the existing specifications but add alternative specifications and provisions that allow increased compliance flexibility with the regulations. For CNG, to comply with the proposed specifications, producers would use the same production processes and the same waste treatment processes as are presently used to comply with the existing regulation. As discussed below, changes in fuel constituents are shifted between CNG and other fuel products already being produced. Thus, additional waste products are not expected to be generated. For LPG, the production, use, and disposal activities have not changed because staff is not proposing any amendment to the LPG specifications. Thus, the proposed amendments are not expected to result in any adverse impact to water quality or waste disposal.

2. Effects on Air Quality

Stationary Sources: For CNG, the MN index will increase the flexibility for gas producers and marketers to comply with the regulations by allowing more variability in the motor vehicle fuel formulations. This could be accomplished through operational changes of existing gas processing methods. These operational changes (e.g., additional extraction) would result in a potential increase in emissions due to additional gas processing. However, these emissions would occur regardless of the proposed amendments since industry must take action to comply with the existing regulations.

One benefit from additional gas processing would be a reduction in the reactivity of the treated natural gas. This would result in lowering the reactivity of gas transmission fugitive emissions and from downstream combustion source emissions by about 20 percent. Staff estimates that about 0.22 tons per day of gas transmission fugitive emissions in the SJV and the SCC would see a reduction in reactivity.[26] The extracted products (e.g. butanes and propanes) would be diverted to supplement LPG production. Thus, the proposed amendments are not expected to increase emissions from the production of the fuel.

Mobile Sources: For CNG, test results show that for dedicated light-duty NGVs, even large variations in fuel composition produced only slight variations, both increases and decreases, in all emissions while bifueled vehicles had only modest changes. Heavy-duty vehicle test data showed that fueling advanced generation technologies with MN 73 fuel produced no discernible impact on PM and NOx emissions when compared to measured emissions with higher CNG fuel quality (greater than MN 80). There were small increases of NMHC emissions of about 10 percent and a six percent increase in CO_2 emissions.

Although there are small increases in NMHC and CO_2 emissions, these increases are expected to be further reduced because, as discussed in Chapter VII, industry's efforts to resolve the CNG quality issue in the SSJV and the SCC will require major gas producers to produce MN 80 CNG. This would effectively make most of the natural gas produced in these regions MN 80; thus, very little MN 73 would likely be available for motor vehicle use. Therefore, no significant impact on air quality is expected.

A concern would exist if the proposed amendments to the CNG fuel specifications were not adopted. In this case, there is a potential for existing CNG fleets and planned CNG fleet proposals to revert back to diesel vehicles. As discussed, conventional diesel vehicles are much more polluting than CNG vehicles even when operating on MN 73 CNG. Thus, not adopting the proposed CNG amendments could adversely impact air quality.

For LPG, emission tests on heavy duty vehicles operating on commercial LPG shows a 14 percent increase in NOx emissions in comparison to motor vehicle grade LPG. There were no discernible changes in other emissions. The WPGA reported that there are less than 500 bobtails operating in Northern California, consuming about two million gallons per year (MM gal/yr) of LPG. Assuming that bobtails fuel on commercial LPG about 70 percent of the time, staff estimates that the potential increase in NOx emissions results in about 0.02 tons per day.[8, 27]

If the proposed amendments are not adopted, existing LPG bobtail delivery vehicles would likely revert back to diesel. Data indicate that PM emissions are significantly greater from diesel vehicles than from LPG vehicles.[28] Therefore, PM emissions may increase above current levels if the proposal amendments are not adopted.

3. Effects of the Staff's Proposal on Greenhouse Gas (GHG) Emissions

The staff's proposal is not expected to significantly increase emissions of greenhouse gases that may contribute to global warming. Global warming is based on the premise that greenhouse gases (carbon dioxide, methane, nitrous oxide, ozone, and others) absorb infrared radiation in the atmosphere, thereby increasing the overall average global temperature. Although there is a small increase in CO_2 exhaust tail-pipe emissions from CNG vehicles running on MN 73, the use of MN 73 CNG is expected to be minimal since most of the CNG produced in the SSJV and the SCC is anticipated to comply with the MN 80 CNG. Also, if the proposed amendments are not adopted, compliance with the existing CNG specifications would require more extensive gas extraction that could generate much more greenhouse gas emissions than if a small amount of vehicles were allowed to use CNG with an MN of 73. Therefore no significant impact on greenhouse gases is expected from the proposed amendments.

4. Public Health

The proposed amendments to the CNG and LPG motor vehicle fuel specifications would cause no significant adverse impact to public health.

5. Potential Effects of Proposed Alternative Fuel Regulations on Allowable Emissions

The proposed amendments to the CNG and LPG regulations will ensure the quality of the fuel for proper engine performance and durability, thus maintaining the emissions benefits of alternative fuels and alternative fuel vehicles.

The minimal increases in emissions of about 10 percent NMHC and six percent CO_2 from a CNG vehicle running on a MN 73 fuel versus a MN 81 fuel must be considered in light of the cleanliness of CNG vehicle emissions compared to gasoline or diesel vehicle emissions. The limited availability of motor vehicle grade CNG in the SSJV and the SCC has resulted in several potential CNG fleets and fueling sites being postponed. In some cases, proponents have elected to revert back to diesel vehicles since there is no certainty in the availability of motor vehicle grade CNG in these regions. If the continued availability of complying CNG due to the proposal prompts the development and sale of new CNG vehicles in lieu of new gasoline or diesel vehicles, the net effect of the proposal could be a decrease in future emissions. If existing CNG use in vehicles were displaced by gasoline (in re-conversions to gasoline prompted by an inadequate CNG supply), current exhaust, evaporative, and gasoline marketing emissions would increase. If re-conversions consisted of diesel vehicles, exhaust emissions of particulate matter and NOx would increase.

For LPG, if the bobtails are allowed to continue operating due to the proposal this will prevent the disruption in the marketplace. In addition, the net effect of the proposal could be a decrease in future emissions from these trucks not reverting back to diesel vehicles. If existing LPG use in bobtails would be displaced by diesel (in re-conversions to diesel prompted by an inadequate LPG supply), exhaust emissions of particulate matter would increase.

X. Economic Impacts of the Proposed Amendments to the Alternative Fuels Regulation

This chapter discusses the economic impacts that would be expected from the implementation of the proposed amendments to the CNG and LPG motor vehicle fuel specifications.

A. Overview of Economic Impact Analysis

As discussed in Chapter IV, the proposed amendments for CNG provide an alternative set of specifications in addition to the existing CNG specifications which adds flexibility and provide more cost-effective compliance options. The proposed amendments for LPG do not change the current LPG fuel specifications but provide an exemption from the fuel specifications for specific delivery vehicles thus making it more economical for LPG suppliers and distributors to market and sell their fuel.

The staff evaluated the economic impacts of the proposed amendments following the requirements of Section 11346.3 of the Government Code. Staff assessed the potential for adverse economic impacts on California business enterprises and individuals, including a consideration of the impact of the proposed regulation on California jobs, business expansion, elimination or creation, and the ability of California business to compete with businesses in other states. The following sections discuss the specific requirements of these statutes and staff's economic impact analysis.

B. Summary of Findings

The staff does not believe that adoption of the proposed amendments would result in significant adverse economic impacts. Consumers, producers, and marketers of vehicular CNG fuel would benefit from the proposed amendments to the CNG motor vehicle fuel specifications. Marketers of LPG fuel would benefit from the proposed amendments to the LPG motor vehicle fuel specifications. The proposed amendments would not significantly alter the profitability of most businesses though it could allow new fueling stations to be brought on-line, thus creating additional jobs. Staff also found no significant adverse fiscal impacts on any local or State agencies.

1. CNG Specifications

The proposed amendments to the CNG motor vehicle fuel specifications would not increase the cost of producing or delivering the fuel and would greatly increase the amount and availability of fuel in the SSJV and SCC that would comply with the specifications. Establishing a methane number of 80 for all natural gas vehicles in general allows compliance of approximately 20 percent of the fuel produced in the SSJV, compared to less than 1 percent compliance with the current specifications. Approximately 20 percent of the fuel produced in the SCC will comply with the methane number 80 specification compared to 11 percent compliance with the current specifications. Establishing an alternative 73 methane number for advanced generation heavy-duty engines and light duty vehicles increases the percentage complying fuel to 99 percent in the SSJV and 88 percent in the SCC and significantly increases the opportunity for siting new light-duty and heavy-duty fleets.[9] In the Los Angeles Basin, all CNG fueling facilities are supplied by imported natural gas that meets the current CNG motor vehicle fuel specifications. Non-complying local gas production in the Los Angeles Basin is used for commercial applications and does not supply CNG fueling facilities.

The proposed amendments would allow producers, distributors and marketers to supply and sell locally produced gas that meets a minimum MN 73 in the SSJV and the SCC without further treatment or blending to CNG fleets with engine technology that can properly operate on this fuel. Engine technology that can properly operate on MN 73 CNG is based solely on the recommendation of the engine manufacturer. Costs related to verifying compliance with the amended specifications are the same as costs to verify compliance with the current specifications.

2. LPG Bobtail Exemption

The proposed amendments to the LPG motor vehicle fuel specifications would not increase the cost of producing or delivering the fuel. These proposed amendments would provide an exemption to allow LPG suppliers and distributors to deliver commercial and motor vehicle grade LPG in the same delivery trucks thus making it more economical to supply fuel to their customers. There are no costs associated with verifying compliance to the proposed exemption.

C. Economic Impacts Analysis on California Businesses as Required by the California Administrative Procedure Act (APA)

1. Legal Requirements

Section 11346.3 of the Government Code requires State agencies to assess the potential for adverse economic impacts on California business enterprises and individuals when proposing to adopt or amend any administrative regulation. The assessment shall include a consideration of the impact of the proposed regulation on California jobs, business expansion, elimination or creation, and the ability of California business to compete with businesses in other states.

2. Findings

Staff's findings show that adoption of the proposed regulatory action would not result in significant adverse impacts on small businesses. The proposed amendments provide more flexibility to the motor vehicle fuel specifications and allow more cost effective options to comply with the regulations. The increased flexibility of the fuel specifications could allow new fueling stations to be sited, thus creating additional jobs.

D. Analysis of Potential Impacts to California State or Local State Agencies

1. Legal Requirements

Section 11346.3 of the Government Code requires State agencies to estimate the costs or savings to any State or local agency and school district in accordance with instructions adopted by the

Department of Finance. The estimate shall include any nondiscretionary costs or savings to local agencies and the costs or savings in federal funding to the State.

2. Findings

Staff has determined that the proposed amendments would not create costs or savings, as defined in Government Code section 11346.5 (a)(6), to any State agency or in federal funding to the State, costs or mandate to any local agency or school district whether or not reimbursable by the State pursuant to Part 7 (commencing with section 17500. Division 4, Title 2 of the Government Code), or other nondiscretionary savings to local agencies. Costs related to verifying compliance with the amended specifications are the same as costs to verify compliance with the current specifications.

E. Analysis of the Cost-Effectiveness and the Impacts on a Cost per Gallon

The proposed amendments provide flexibility and provide more cost-effective compliance options. Consequently, staff believes that there will be no adverse impact on fuel cost. The alternative considered was to leave the current regulations unchanged. The compliance costs associated with the current regulations are higher than those projected with the proposed amendments.

XI. References

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Appendices

APPENDIX A

PROPOSED REGULATION ORDER

AMENDMENTS TO SECTIONS 2290, 2291, 2292.5 AND 2292.6, TITLE 13, CALIFORNIA CODE OF REGULATIONS, REGARDING THE COMPRESSED NATURAL GAS AND LIQUEFIED PETROLEUM GAS SPECIFICATIONS IN THE ALTERNATIVE FUELS FOR MOTOR VEHICLE REGULATIONS

The text of the proposed amendments is shown in underline to indicate additions and ~~strikeout~~ to indicate deletions, compared to the preexisting regulatory language.

Amend section 2290, title 13, California Code of Regulations, to read as follows:

§ 2290. Definitions.

(a) For the purposes of this article, the following definitions apply:
(1) "Alternative fuel" means any fuel which is commonly or commercially known or sold as one of the following: M-100 fuel methanol, M-85 fuel methanol, E-100 fuel ethanol, E-85 fuel ethanol, compressed natural gas, liquefied petroleum gas, or hydrogen.
(2) "ASTM" means the American Society for Testing Materials.
(3) "Bobtail truck" means any liquefied petroleum gas transportation truck capable of being run off the fuel from the cargo tank with a maximum cargo capacity of 3000 gallons.
~~(3)~~(4) "Motor vehicle" has the same meaning as defined in section 415 of the Vehicle Code.
(5) "South Central Coast" for the purpose of the CNG specifications is defined as San Luis Obispo and Santa Barbara County.
(6) "Southern San Joaquin Valley" for the purpose of the CNG specifications means the following areas within the San Joaquin Valley Air Pollution Control District: Fresno, Kings, and Tulare Counties and the western portion of Kern County.
~~(4)~~(7) "Supply" means to provide or transfer a product to a physically separate facility, vehicle, or transportation system.

NOTE

Authority cited: Sections 39600, 39601, 43013, 43018, ~~and~~ 43101, and 43806, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975). **Reference:** Sections 39000, 39001, 39002, 39003, 39010, 39500, 40000, 43000, 43016, 43018 ~~and~~ 43101, and 43806, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975).

Amend section 2291, title 13, California Code of Regulations, to read as follows:

§ 2291. Basic Prohibitions.

(a) Starting January 1, 1993, no person shall sell, offer for sale or supply an alternative fuel intended for use in motor vehicles, excluding LPG bobtail trucks, in California unless it conforms with the applicable specifications set forth in this article 3.

(b) An alternative fuel shall be deemed to be intended for use in motor vehicles in California if it is:

(1) stored at a facility which is equipped and used to dispense that type of alternative fuel to motor vehicles, or

(2) delivered or intended for delivery to a facility which is equipped and used to dispense that type of alternative fuel to motor vehicles, or

(3) sold, offered for sale or supplied to a person engaged in the distribution of motor vehicle fuels to motor vehicle fueling facilities, unless the person selling, offering or supplying the fuel demonstrates that he or she has taken reasonably prudent precautions to assure that the fuel will not be used as a motor vehicle fuel in California.

(c) For the purposes of this section, each retail sale of alternative fuel for use in a motor vehicle, and each supply of alternative fuel into a motor vehicle fuel tank, shall also be deemed a sale or supply by any person who previously sold or supplied such alternative fuel in violation of this section.

NOTE

Authority cited: Sections 39600, 39601, 43013, 43018, ~~and~~ 43101, and 43806, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975). Reference: Sections 39000, 39001, 39002, 39003, 39010, 39500, 40000, 43000, 43016, 43018 ~~and 43101~~, 43101, and 43806, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975).

SPECIFICATIONS FOR COMPRESSED NATURAL GAS

Amend section 2292.5, title 13, California Code of Regulations, to read as follows:

§ 2292.5 Specifications for Compressed Natural Gas.

The following Standards apply to compressed natural gas
(The identified test methods are incorporated herein by reference):

~~Specifications for Compressed Natural Gas~~
Motor Vehicle Compressed Natural Gas Fuel must meet one of the following specifications:

A. Statewide Specifications

Specification	**Value**	**Test Method**
Hydrocarbons (expressed as mole percent)		
Methane	88.0% (min.)	ASTM D 1945-96~~81~~
Ethane	6.0% (max.)	ASTM D 1945-96~~81~~
C_3 and higher HC	3.0% (max.)	ASTM D 1945-96~~81~~
C_6 and higher HC	0.2% (max.)	ASTM D 1945-96~~81~~
Other Species (expressed as mole percent unless otherwise indicated)		
Hydrogen	0.1% (max.)	ASTM D 2650-88
Carbon Monoxide	0.1% (max.)	ASTM D 2650-88
Oxygen	1.0% (max.)	ASTM D 1945-96~~81~~
Inert Gases		
Sum of CO_2 and N_2	1.5-4.5% (range)	ASTM D 1945-96~~81~~
Water	[a]	
Particulate Matter	[b]	
Odorant	[c]	
Sulfur	16 ppmv by vol. (max.)	Title 17 CCR Section 94112

[a] The dewpoint at vehicle fuel storage container pressure shall be at least 10 °F below the 99.0% winter design temperature listed in Chapter 24, Table 1, Climatic Conditions for the United States, in the American Society of Heating, Refrigerating and Air Conditioning Engineers ~~Engineer's~~ (ASHRAE) Handbook, 1989 fundamentals volume. Testing for water vapor shall be in accordance with ASTM D 1142-90, utilizing the Bureau of Mines apparatus.
[b] The compressed natural gas shall not contain dust, sand, dirt, gums, oils, or other substances in an amount sufficient to be injurious to the fueling station equipment or the vehicle being fueled.
[c] The natural gas at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air or not over 1/5 (one-fifth) of the lower limit of flammability.

B. Statewide Alternative Specifications

Specification[a]	**Value**	**Test Method**
Methane Number[b]	80	ASTM 1945-96

[a] This specification may be used as an alternative to the "Hydrocarbons" portion of the Statewide Specification in part A. All of the specifications under the title "Other Species" must be met to comply with the regulation.

[b] Methane Number is determined by the following calculation:

$$MN = 1.624*(-406.14+508.04*RHCR-173.55*RHCR^2+20.17*RHCR^3)-119.1$$

Where RHCR= (% methane*4 + % ethane*6 + % propane*8+(% isobutane + % n-butane)*10 + (% isopentane + n-pentane)*12+ (% hexane and longer hydrocarbon chains) *14) /(% methane*1+% ethane*2+ % propane*3+(% isobutane + % n-butane)*4+(% isopentane + % n-pentane)*5+% (hexane and longer hydrocarbon chains)*6).

C. Limited Area Alternative Specifications

This specification is limited to fueling facilities that meet the following conditions:

1) The fueling station is located in one of the following counties: San Luis Obispo, Santa Barbara, Ventura, Kings, Fresno, Tulare, and the portion of Kern that is in the San Joaquin Valley Air Pollution Control District;
2) The natural gas service provider does not provide natural gas that meets an MN of 80 at the service connection;
3) The fleet vehicles can operate on CNG with a MN of 73 as recommended and documented by the engine manufacturer; and
4) The fueling station has controls in place that will prevent misfueling.

Specification [a]	**Value**	**Test Method**
Methane Number [b]	73 (min.)	ASTM D 1945-96

[a] This specification may be used as an alternative to the "Hydrocarbons" portion of the Statewide Specification in part A. All of the specifications under the title "Other Species" must be met to comply with the regulation.

[b] Methane Number is determined by the following calculation:

$$MN = 1.624*(-406.14+508.04*RHCR-173.55*RHCR^2+20.17*RHCR^3)-119.1$$

Where RHCR= (% methane*4 + % ethane*6 + % propane*8+(% isobutane + % n-butane)*10 + (% isopentane + n-pentane)*12+ (% hexane and longer hydrocarbon chains) *14) /(% methane*1+% ethane*2+ % propane*3+(% isobutane + % n-butane)*4+(% isopentane + % n-pentane)*5+% (hexane and longer hydrocarbon chains)*6).

NOTE

Authority cited: Sections 39600, 39601, 43013, 43018, ~~and~~ 43101, and 43806, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975). Reference: Sections 39000, 39001, 39002, 39003, 39010, 39500, 40000, 43000, 43016, 43018~~ and 43101~~, 43101, and 43806, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975).

SPECIFICATIONS FOR LIQUEFIED PETROLEUM GAS

Amend section 2292.6 title 13, California Code of Regulations, to read as follows:

§ 2292.6. Specifications for Liquefied Petroleum Gas

The following Standards apply to liquefied petroleum gas
(The identified test methods are incorporated herein by reference):

Specification	Value	Test Method
Propane	85.0 vol. % (min.) [a]	ASTM D 2163-87
Vapor Press. at 100° F	208 psig (max.)	ASTM D 1267-89 ASTM D 2598-88 [b]
Volatility residue:		
Evaporated temp., 95%	-37 ° F (max.)	ASTM D 1837-86
or		
butanes	5.0 vol. % (max.)	ASTM D 2163-87
Butenes	2.0 vol. % (max.)	ASTM D 2163-87
Pentenes and heavier	0.5 vol. % (max.)	ASTM D 2163-87
Propene	10.0 vol. % (max.)	ASTM D 2163-87
Residual matter:		
Residue on evap. of 100 ml	0.05 ml (max.)	ASTM D 2158-89
Oil stain observed.	Pass [c]	ASTM D 2158-89
Corrosion, copper strip	No. 1 (max.)	ASTM D 1838-89
Sulfur	80 ppmw (max.)	ASTM D 2784-89
Moisture content	Pass	ASTM D 2713-86
Odorant	[d]	

[a] Propane shall be required to be a minimum of 80.0 volume percent starting on January 1, 1993. Starting on January 1, 1999, the minimum propane content shall be 85.0 volume percent.

[b] In case of dispute about the vapor pressure of a product, the value actually determined by Test Method ASTM D 1267-89 shall prevail over the value calculated by Practice ASTM D 2598-88.

[c] An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper, in 0.1 ml increments and examined in daylight after 2 min. as described in Test Method ASTM 2158-89.

The liquefied petroleum gas upon vaporization at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air of not over 1/5 (one-fifth) of the lower limit of flammability.

Within five years from the effective date of adoption or implementation, whichever comes later, of the amendments approved December 11, 1998, the Air Resources Board, in consultation with the Secretary for Environmental Protection, shall review the provisions of this chapter to determine whether it should be retained, revised or repealed.

NOTE

Authority cited: sections 39600, 39601, 43013, 43018, ~~and~~ 43101, and 43806, Health and Safety Code; and Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975). Reference: sections 39000, 39001, 39002, 39003, 39010, 39500, 40000, 43000, 43016, 43018, ~~and~~ 43101, and 43806, Health and Safety Code; and Western Oil and Gas Ass'n v. Orange County Air Pollution Control District, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975).

Appendix B - Overview and Results of CNG Emission Testing Programs

A. Background

Two studies have been conducted to evaluate CNG fuel quality effects on light-duty and heavy-duty vehicle driveability, emissions, and fuel economy. These studies are referred to as the Natural Gas Vehicle Technology and Fuel Performance Evaluation Program (PEP).

The PEP studies were supported by a collaborative group that included the Gas Research Institute (GRI), Pacific Gas & Electric (PG&E), Southern California Gas Company (SoCalGas), Atlanta Gas Light Company (AGL), U.S. Environmental Protection Agency (EPA), Air Resources Board (ARB), and auto manufacturers. The Clean Air Vehicle Technology Center (CAVTC) was contracted to conduct the testing and data evaluation. The results from these studies are documented in a light-duty vehicle test report,[1] completed in 1997, and a heavy-duty data presentation,[2] presented in 2000.

B. Light Duty Test Program

1. Test Protocol

The light-duty testing included emissions tests, fuel economy tests, including highway and acceleration, and driveability tests.[1] The emissions tests used the standard 3-phase Federal Test Procedure (FTP) test cycle and the additional acceleration phase (US06) from the proposed supplemental FTP cycle presented by the United States Environmental Protection Agency (U.S. EPA) in 1994. Each test was run twice for each vehicle/fuel combination to determine test repeatability. The measured emissions included total hydrocarbons (THC), methane (CH4), non-methane organic gases (NMOG), nitrogen oxides (NOx), carbon monoxide (CO), and carbon dioxide (CO_2). The vehicles tested included both dedicated NGVs (designed to use only CNG fuel) and bi-fuel vehicles. Some of these NGVs were designed and built by OEMs and others were after-market conversions, as shown in Table B-1 below. The Dodge Dakota vehicle was unique in that it was a bi-fuel prototype designed and built by an OEM. The emissions data for the individual vehicles are provided in Attachment B-1 at the end of this appendix.

Table B-1: Light-Duty Vehicle Testing - Vehicles

Year	Make & Model	Type	OEM	Conversion
1994	Dodge Caravan	Dedicated	X	
1994	Dodge Ram Van	Dedicated	X	
1992	Ford Crown Victoria	Dedicated	X	
1993	Honda Accord	Dedicated	X	
1994	GMC Sierra (Cardinal)	Dedicated		X
1992	GMC Sierra (PAS)	Dedicated		X
1995	Ford F250 (QVM)	Bi-fuel		X
1994	Dodge Dakota	Bi-fuel	X	

The fuels tested, shown in Table B-2, covered Wobbe numbers and methane numbers inclusive of the variation of the gas produced in the South Central Coast and Southern San Joaquin Valley. The current CNG motor vehicle fuel specifications are included in the last column of this table for comparison. Methane numbers of the tested fuels ranged from approximately 63 to 100 and Wobbe numbers from 1425 to 1182. The gas compositions were speciated out to C4+. The C4+ was assumed to be butane for the calculation of the methane number. Only TF-5 had a significant C4+ content. If the C4+ actually included heavier hydrocarbons than butane, the MN of the test fuel would be lower than reported. Methane content for the fuels ranged from 82 percent to 94 percent, ethane content from two percent to eight percent and C3+ from zero percent to 10 percent.

Table B-2: Light-Duty Vehicle Testing - Fuels

Mole %	TF-1	TF-2	TF-3	TF-4	TF-5	Current Spec
Methane	91.44	90.04	84.89	94.97	82.38	88.0 min
Ethane	1.75	4.0	8.44	3.02	4.65	6.0 max
Propane	0.00	C3+ = 2.0	0.00	0.14	6.00	C3+ = 3.0 max
C4+	0.02		0.00	0.06	4.07	
Inerts	6.78	3.5	6.40	1.79	2.89	1.5-4.5
Oxygen	0.01	0.5	0.27	0.02	0.02	1.0 max
MN*	103	89	88	99	63	NA
Wobbe	1245	1182	1284	1341	1425	NA

*ARB staff calculation

2. Test Results

Figure B-1, Figure B-2, and Figure B-3 below show the variation of NOx, CO and NMOG emissions as measured with the FTP cycle for the OEM dedicated light-duty vehicles as a function of fuel methane number. Applicable ARB 50,000 mile ultra low-emissions vehicle (ULEV) standards for the vans and for the passenger cars are shown in these figures for reference. The higher ULEV standards correspond to the two vans, the Caravan and the Ram, while the lower ULEV standards correspond to the two passenger cars, the Accord and Crown Victoria. These standards are only applicable to the FTP test cycle emissions. The emissions from all the OEM dedicated vehicles were below the applicable ULEV standard with each of the tested fuels. Additionally, the NMOG values in Figure B-3 have not been adjusted by the natural gas reactivity adjustment factor of 0.41. Applying this adjustment factor drops these values an additional 60 percent.[1]

Figure B-1: Measured NOx Emissions from Dedicated Light-Duty Vehicles with the FTP Test Cycle

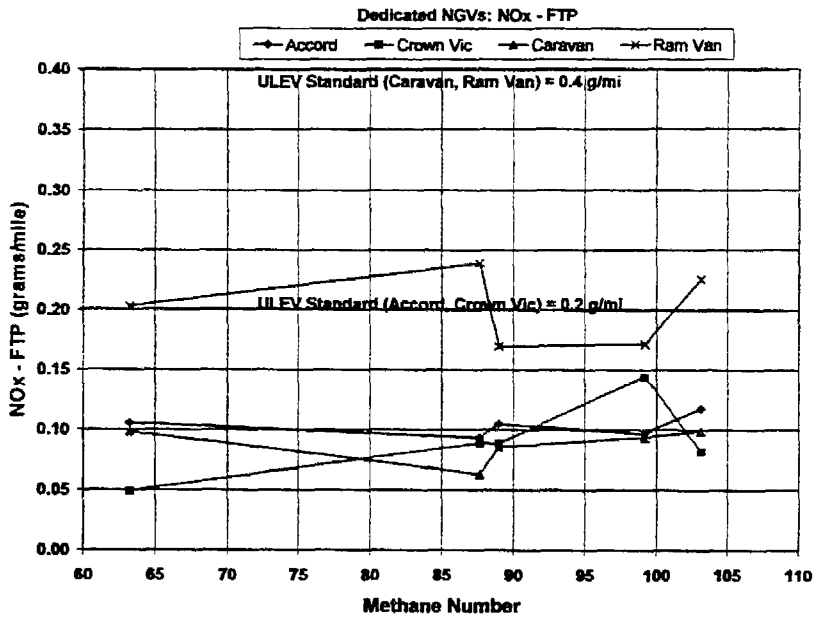


Figure B-2: Measured CO Emissions from Dedicated Light-Duty Vehicles with the FTP Test Cycle

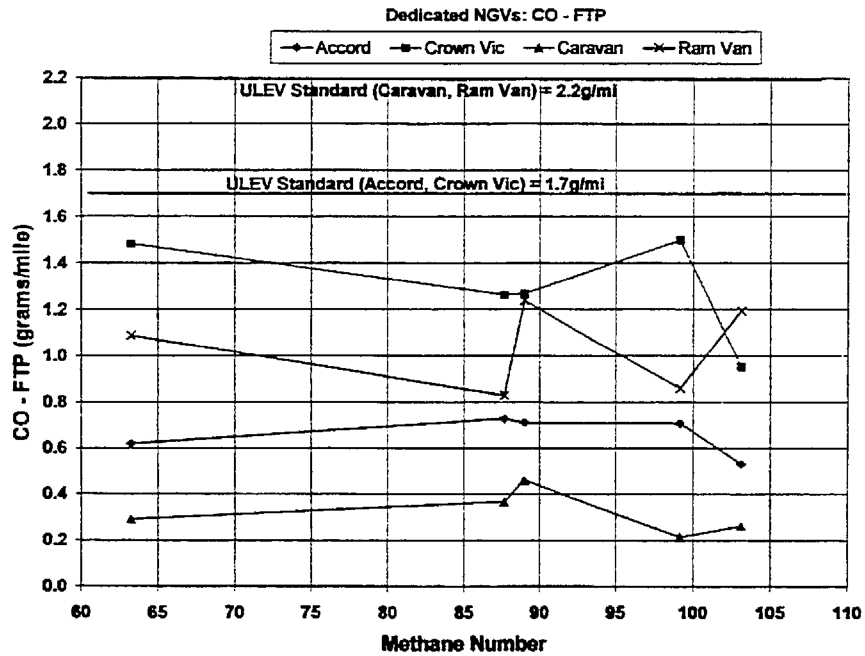


Figure B-3: Measured NMOG Emissions from Dedicated Light-Duty Vehicles with the FTP Test Cycle

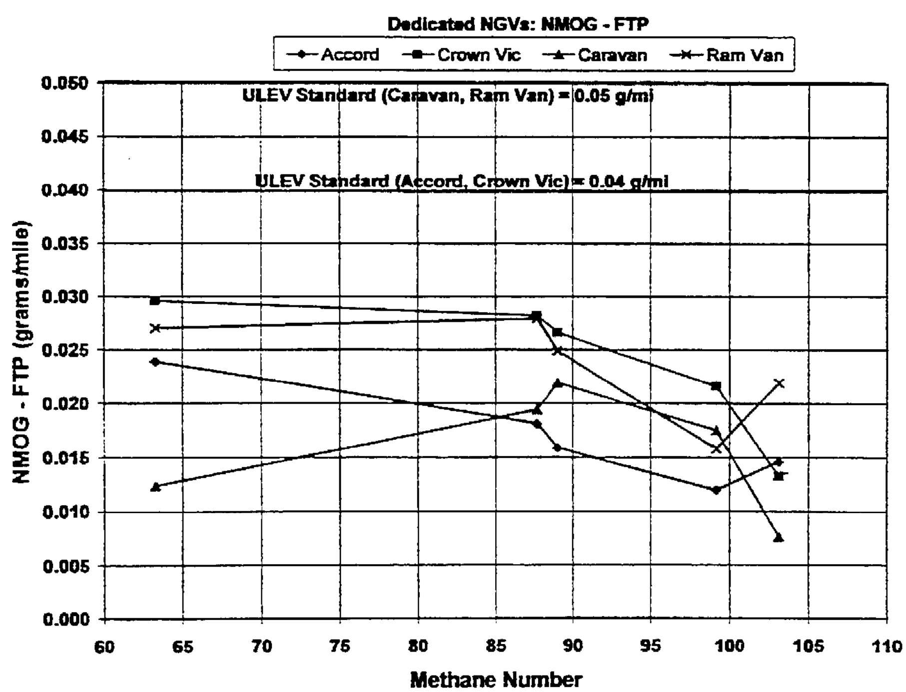


Figure B-4, Figure B-5, and Figure B-6 below show the variation of NOx, CO and NMOG emissions for the after-market conversion dedicated and bi-fuel light-duty vehicles as a function of fuel methane number as measured with the FTP cycle. The OEM prototype bi-fuel Dodge Dakota is included in these figures. The ARB 50,000 mile ultra low-emissions vehicle (ULEV) standard, low emissions vehicle (LEV) standard, and transitional low emission vehicle (TLEV) standard for the this vehicle type (light-duty trucks, 3751-5750 lbs.) are shown in these figures for comparison. Again, these standards are only applicable to the FTP test cycle emissions.

As shown in the figures below, the after-market conversion vehicles and the OEM prototype bi-fuel vehicle had higher emissions and more variation in emissions with fuel quality than the OEM dedicated fuel vehicles. However, all of these vehicles had NMOG emission levels within the LEV standard and NOx levels that were at or near the TLEV standard. Three of the four vehicles also met the TLEV/LEV CO emissions standard. The GMC (PAS), an after-market conversion dedicated vehicle, had CO emissions that were consistently higher than the standard for all tested fuels.

Figure B-4: Measured NOx Emissions from After-market Conversion and OEM Prototype Light-Duty Vehicles with the FTP Test Cycle

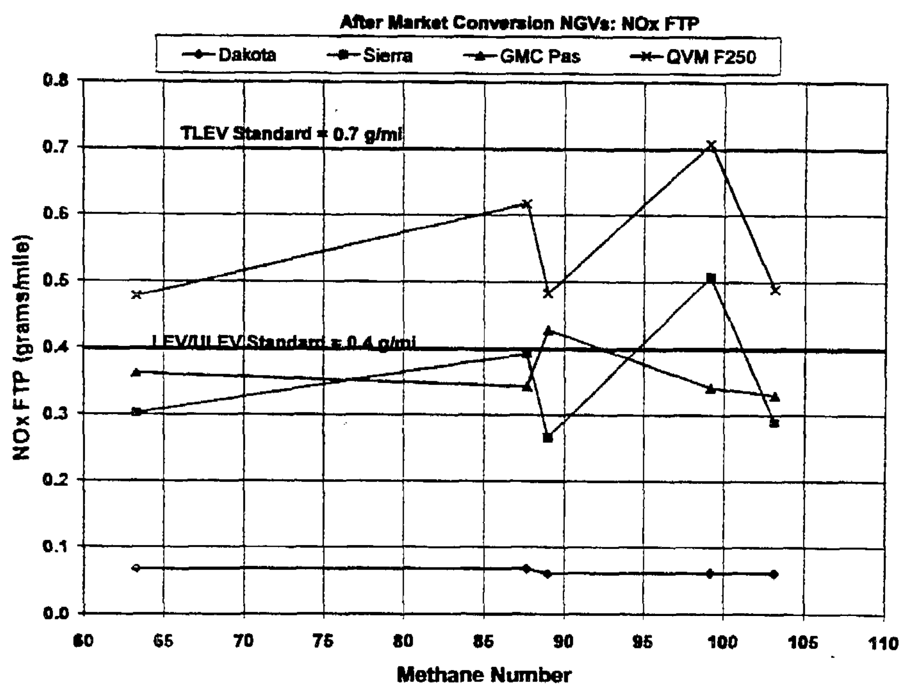


Figure B-5: Measured CO Emissions from After-market Conversion and OEM Prototype Light-Duty Vehicles with the FTP Test Cycle

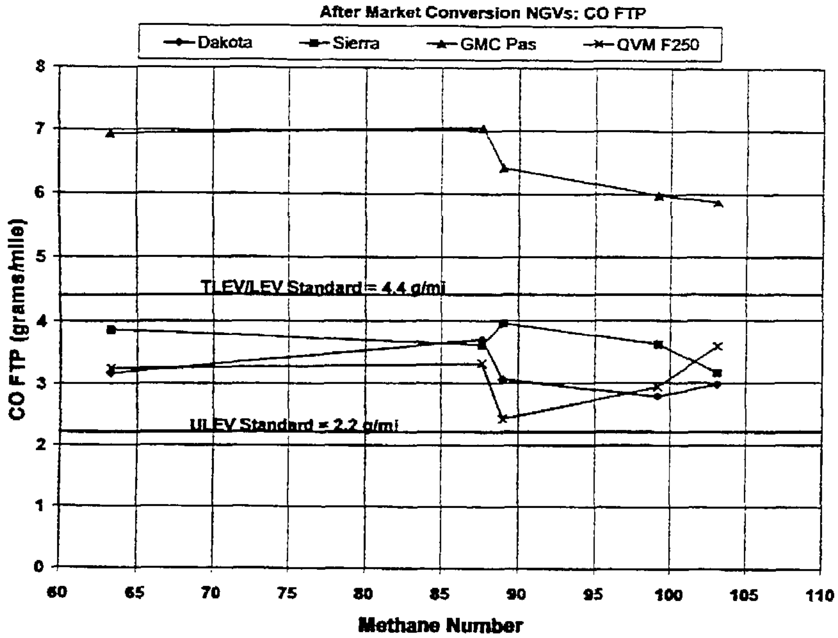


Figure B-6: Measured NMOG Emissions from After-market Conversion and OEM Prototype Light-Duty Vehicles with the FTP Test Cycle

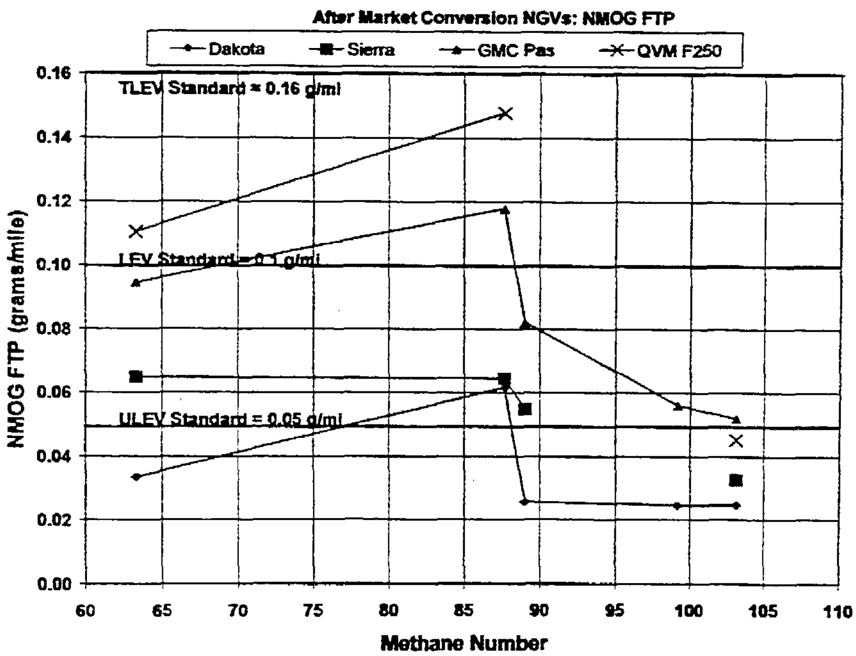
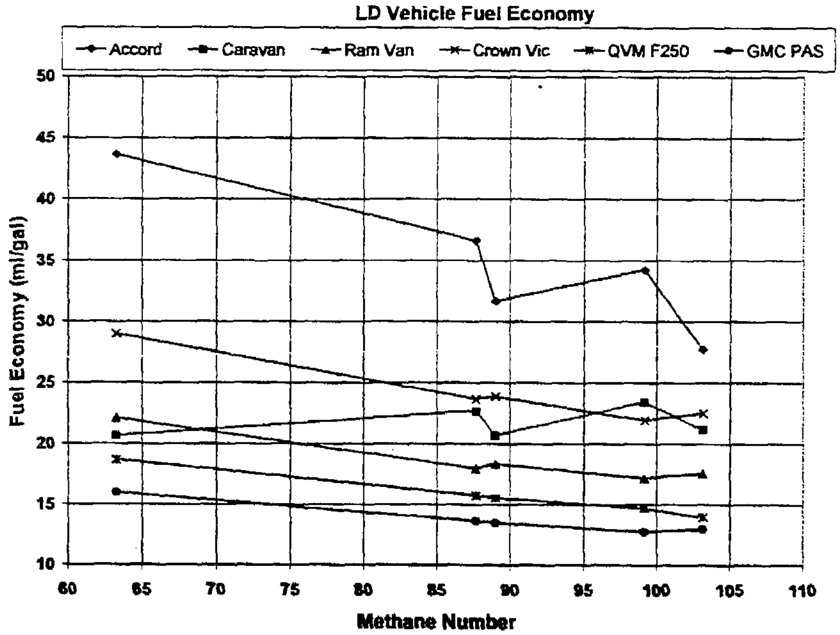


Figure B-7 below shows that fuel economy was either insensitive to fuel quality or increased with the reduced methane number.

Figure B-7: Measured Fuel Economy with Light Duty Vehicles with the FTP Test Cycle



C. Heavy Duty Test Program

1. Test Protocol

The heavy-duty vehicle testing evaluated emissions, fuel economy, and performance of seven different HD vehicles with four different fuels.[2] Testing included three different drive cycles with three tests run for each cycle/fuel/vehicle combination. The three drive cycles used were the EPA Heavy-Duty Urban Dynomometer Driving Schedule (UDDS), the Commuter cycle, and the Modified Central Business District (Mod-CBD) cycle. The measured emissions included total hydrocarbons (THC), methane (CH4), non-methane hydrocarbons (NMHC), nitrogen oxides (NOx), carbon monoxide (CO), and carbon dioxide (CO_2). The seven vehicles tested included both open loop and closed loop technology engines, as shown in Table B-3 below. The closed loop technology engines are designated as either advanced or first generation in Table B-3. The Cummins closed loop technology engine is considered first generation closed loop technology and is not as adaptable to variable fuel quality as the advanced generation closed loop technology engines such as the John Deere.

Table B-3: Heavy-Duty Vehicle Testing - Vehicles

Year	Make & Model	Duty	Control
1997	John Deer 8.1L	School Bus	Closed Loop, Advanced
1999	Cummins 8.3L	School Bus	Closed Loop, First Generation
1996	John Deere 6.8L	School Bus	Closed Loop, Advanced
1999	John Deere 8.1L	Crew Truck	Closed Loop, Advanced
1996	Detroit Diesel 8.5L Series 50	Transit Bus	Open Loop
1996	Cummins 10.0L	Transit Bus	Open Loop
1999/2000	Detroit Diesel 12.7L Series60G(LNG)*	Tractor	Closed Loop, First Generation

* Omitted from the data due to inconsistent data trends

The fuel qualities tested, shown in Table B-4, had methane contents ranging from 82 percent to 95 percent, ethane content from 3 percent to 8 percent and C3+ from 0 percent to 5 percent. The Wobbe numbers for the tested fuels ranged from 1310 to 1360 and methane numbers from 73 to 99. The methane number range included the lowest recommended fuel quality for advanced generation closed loop technology heavy-duty engines, methane number 73. The highest methane number fuel, labeled High Quality, meets the current CNG motor vehicle fuel specifications and exceeds the proposed specification of MN 80. The methane number calculated for the high ethane fuel, MN 81, is in the range of the calculated methane number for gas that meets the current specifications, MN ~ 80 – 82, as shown in Table D-1 in Appendix D. Although this high ethane fuel does not meet the current specifications, due to the slightly low methane content and the high ethane content, the emissions data using this fuel can be equated to a fuel that would meet the proposed MN 80 specification.

Table B-4: Heavy-Duty Vehicle Testing - Fuels

Mole %	High C3+	High Inerts/C3+	High Ethane	High Quality*	Current Spec
Methane	87.25	82.06	87.11	94.97	88.0 min
Ethane	5.84	7.11	8.25	3.02	6.0 max
Propane	3.06	3.83	1.81	0.14	C3+ = 3.0 max
Iso-butane	0.28	0.35	0.09	0.02	
N-butane	0.55	0.17	0.17	0.02	
Iso-pentane	0.08	0.06	0.02	0.01	
N-pentane	0.07	0.04	0.02	0.01	
C6+	0.05	0.0	0.01	0.0	
Inerts	2.82	5.92	2.52	1.81	1.5-4.5
Oxygen	0.0	0.0	0.0	0.03	1.0 max
MN**	77	73	81	99	~80-82***
Wobbe**	1363	1310	1359	1338	

* Meets current specification
** ARB staff calculation
***No current requirement for MN

Three tests were run for each cycle/fuel/vehicle combination for test repeatability. One exception to this was the 1996 8.5L Detroit Diesel Series 50 open loop technology transit bus tested with the UDDS cycle, where only two tests per fuel were completed. The other exception was the absence of particulate emissions data for 1997 8.1L John Deere closed loop technology school bus with the high ethane fuel. Only one measurement was available for this fuel/vehicle combination for the UDDS cycle. No data was available for this fuel/vehicle combination for the other two test cycles.

2. Test Results

The emissions and fuel economy results shown in the following tables and figures are for the UDDS driving schedule. The UDDS driving schedule generally resulted in the highest emissions levels as well as the highest fuel consumption.[3] Figure B-5 through Table B-7 below summarize the emissions data for each technology group. These tables give the range observed for each pollutant with each fuel quality. Table B-6 does not give a range since the first generation closed loop technology group was represented by a single vehicle. The emissions data for the individual vehicles are provided in Attachment B-1 at the end of this appendix. An average value for each cycle/fuel/vehicle combination is given in the attachment.

Table B-5: Advanced Generation Closed Loop Technology Engine Emissions and Fuel Economy Comparison of MN99, MN81, and MN73 CNG

Advanced Generation Closed Loop Technology, Vehicles # 1,3,4 only						
Test Fuel MN	**99**		**81**		**73**	
Tailpipe emissions (grams/mile)	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
THC	8.0	8.6	7.5	7.9	7.5	8.2
CO	0.3	3.8	0.2	4.2	0.2	4.2
NOx	6.0	11.4	6.9	12.8	6.1	11.0
CO_2	910	980	944	1020	978	1077
NMHC	0.4	2.0	1.3	2.7	1.5	3.0
PM	0.013	0.032	0.009	0.029	0.008	0.031
(Mi/Gal.)	6.1	7.3	7.6	7.7	8.0	8.3

Table B-6: First Generation Closed Loop Technology Engine Emissions and Fuel Economy Comparison of MN99, MN81, and MN73 CNG

First Generation Closed Loop Technology, Vehicle # 2 only			
Test Fuel MN	**99**	**81**	**73**
Tailpipe emissions (grams/mile)			
THC	9.6	7.2	7.3
CO	0.7	0.7	0.8
NOx	10.3	12.4	12.4
CO_2	1070	1098	1144
NMHC	1.9	1.8	1.9
PM	0.066	0.043	0.039
(Mi/Gal.)	6.1	6.7	7.0

Table B-7: Open Loop Technology Engine Emissions and Fuel Economy Comparison of MN99, MN81, and MN73 CNG

Open Loop Technology, Vehicles # 5 and 6 only						
Test Fuel MN	**99**		**81**		**73**	
Tailpipe emissions (grams/mile)	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
THC	5.2	11.0	5.3	9.1	5.2	12.8
CO	0.04	4.6	0.1	5.0	0.1	5.0
NOx	6.4	14.2	16.7	20.8	7.5	18.0
CO_2	1167	1259	1290	1469	1336	1478
NMHC	1.0	2.4	1.3	3.0	1.3	4.7
PM	0.025	0.035	0.033	0.051	0.021	0.055
(Mi/Gal.)	5.1	5.7	5.1	5.7	5.2	6.1

The closed loop technology 12.7L Detroit Diesel LNG tractor was omitted from the data presented because its CO and PM data trends were inconsistent with the other closed loop technology engine data. The LNG tractor PM emissions were over 10 times higher than those for the other engines, independent of fuel quality. Additionally, the LNG tractor CO emissions varied much more significantly with fuel quality than those from the other closed loop technology engines. However, this data can be found in Attachment B-1.

The PM emissions for the open and closed loop technology engines are shown in Figure B-8 and Figure B-9 versus methane number. Both the closed loop and the open loop technology engine PM emissions were 0.07 grams/mile or less with the majority of the data in the 0.02 to 0.04 gram/mile range. The typical PM variation with fuel quality seen in this data, 0.02 grams/mile, was not significantly different from the test to test variations seen within the data sets.

Figure B-8: PM Emissions for Open Loop Technology Engines

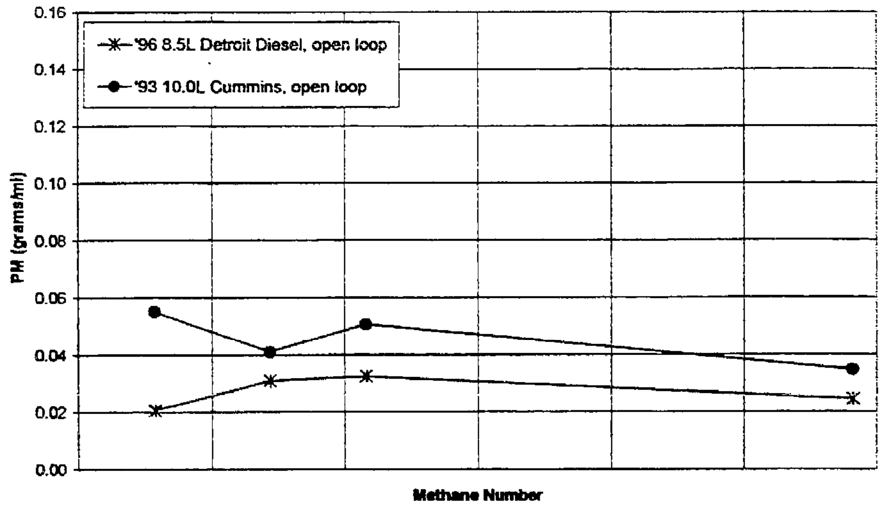
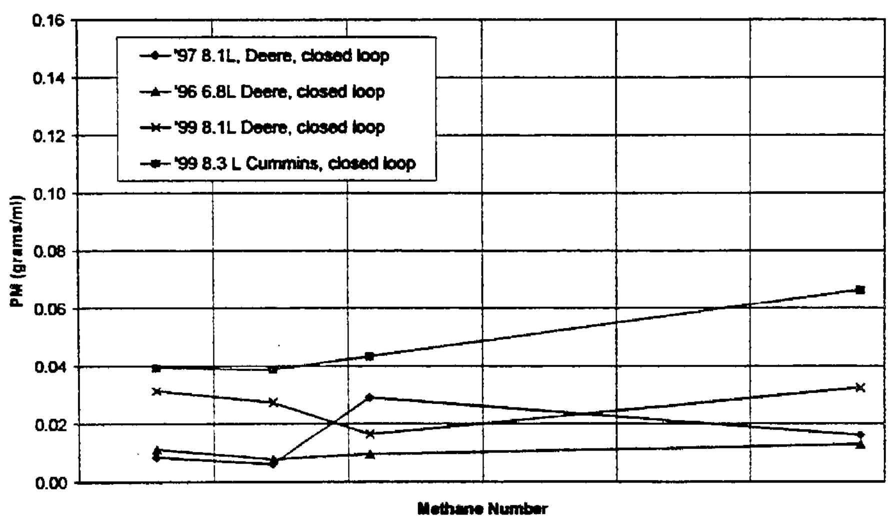


Figure B-9: PM Emissions for Closed Loop Technology Engines



NOx emissions for the open loop technology engines, shown in Figure B-10, were higher and had significantly more variation with fuel quality than those measured with the closed loop technology engines, shown in Figure B-11. The NOx emissions with the high quality MN99 fuel were similar in value between the open loop and closed loop technology engines. However, the open loop technology engines indicated an increase in

NOx emissions with reduced methane number that was not evident with the either the first generation or the advanced generation closed loop technology engines.

Figure B-10: NOx Emissions for Open Loop Technology Engines

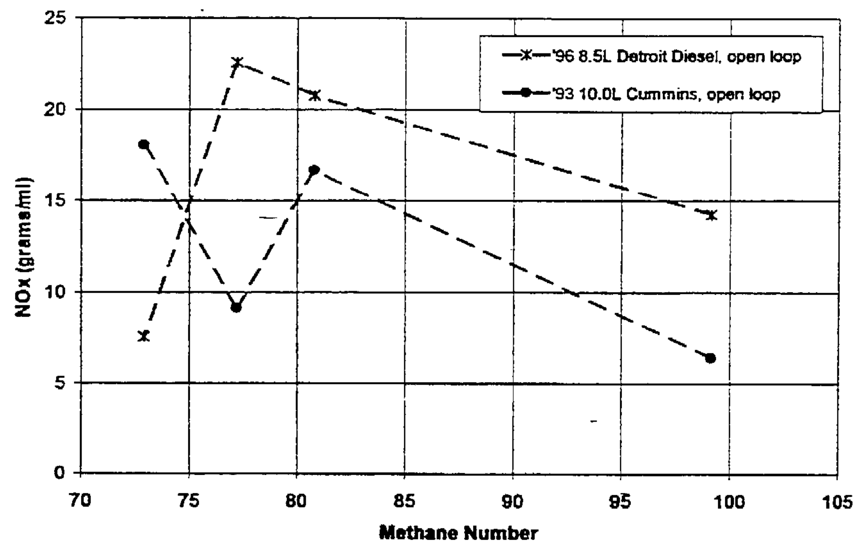
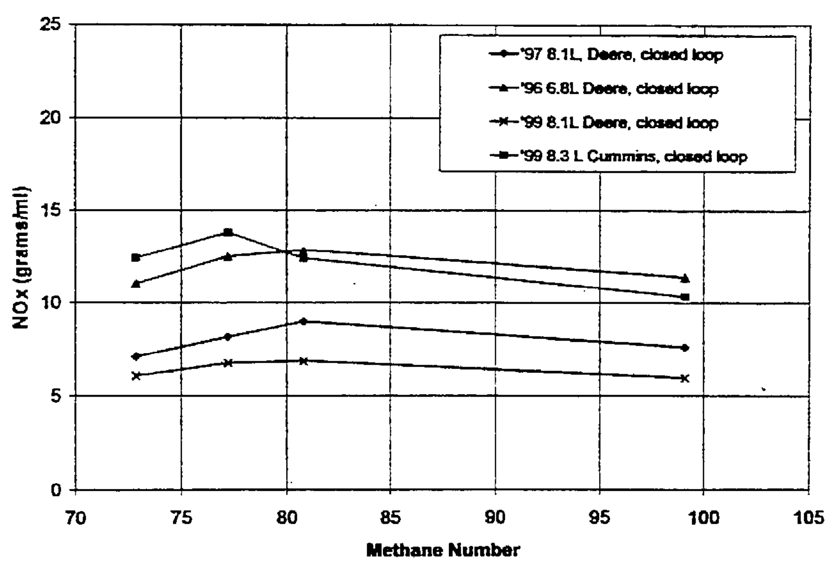


Figure B-11: NOx Emissions for Closed Loop Technology Engines



Non-methane hydrocarbon emissions trends with fuel quality, see Figure-B-12 and Figure B-13, were similar for the open loop and closed loop technology engines. Both technologies indicated some increases in emissions with decreasing fuel quality. The Detroit Diesel open loop technology engine exhibited a larger increase in NMHC emissions with the MN73 fuel than any of the other engines. The advanced generation technology engines showed the most consistent trends from vehicle to vehicle with approximately a 10 percent increase from MN81 fuel quality to MN73 fuel quality.

Figure B-12: NMHC Emissions for Open Loop Technology Engines

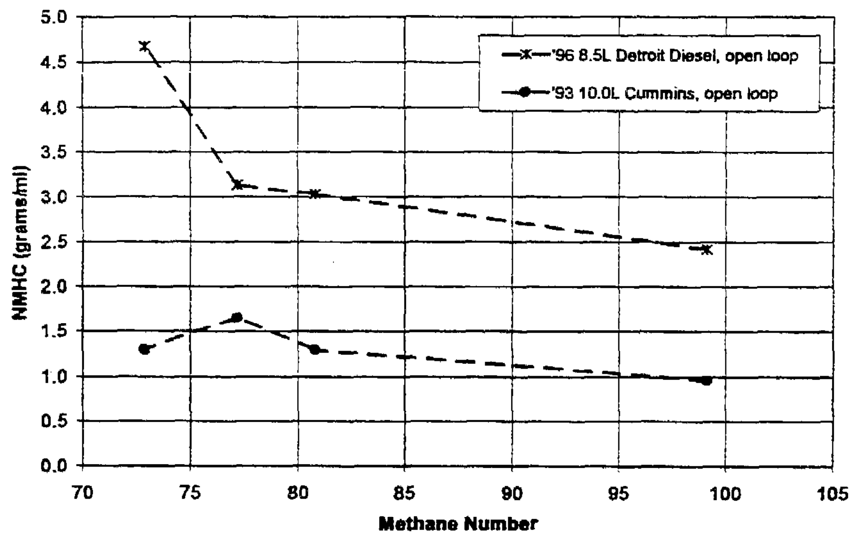
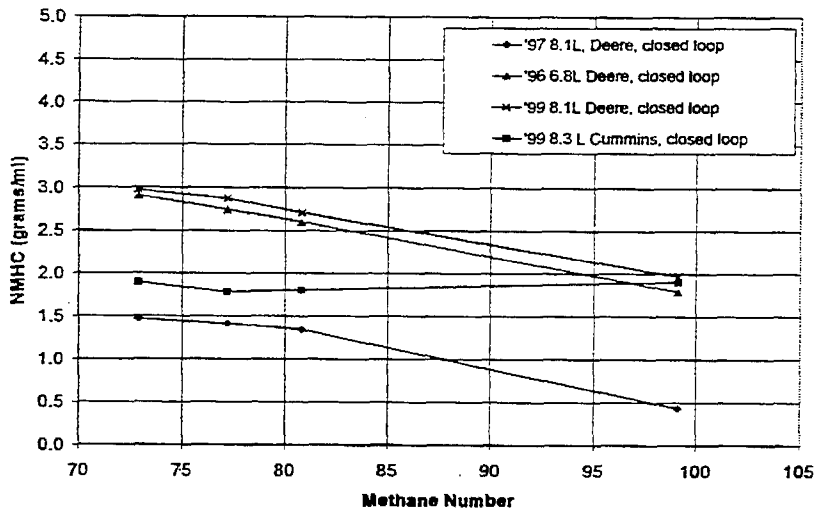


Figure B-13: NMHC Emissions for Closed Loop Technology Engines



THC emissions for both open and closed loop technology engines are shown in Figure B-14 and Figure B-15 below. With the exception of the Detroit Diesel open loop technology vehicle, there was minimal THC emissions variation with fuel quality. The Cummins open loop technology engine actually produced lower THC emissions, 5 to 6 grams/mile, than any of the closed loop technology engines. The THC emissions from all four of the closed loop technology engines were tightly grouped together at approximately 8 grams/mile.

Figure B-14: THC Emissions for Open Loop Technology Engines

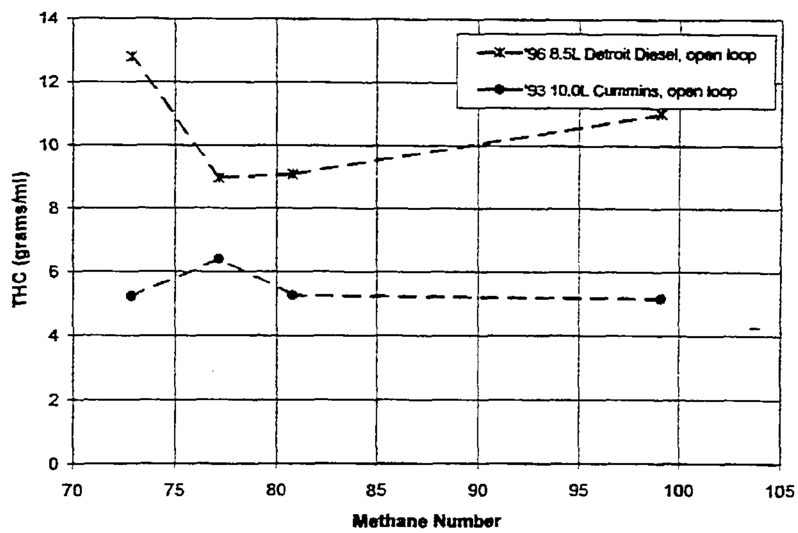
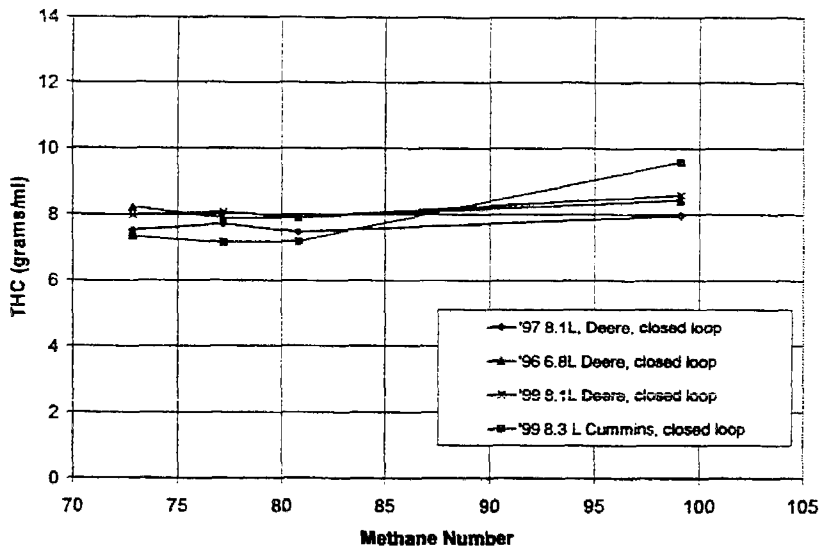


Figure B-15: THC Emissions for Open Loop Technology Engines



CO emissions for both open and closed loop technology engines, shown in Figure B-16 and Figure B-17, did not vary significantly with the variation of fuel quality. However, there was a significant difference between the CO emissions for the different engines. Both the first generation closed loop technology Cummins vehicle and the open loop technology Cummins engine as well as one of the advanced technology closed loop technology engines, the 1997 8.1L John Deere school bus, all had measured CO emissions of less than 1 gram/mile. The other two advanced technology closed loop technology engines had CO emissions of approximately 3 to 4 grams/mile. The Detroit Diesel open loop technology engine produced CO emissions of 4 to 5 grams/mile.

Figure B-16: CO Emissions for Open Loop Technology Engines

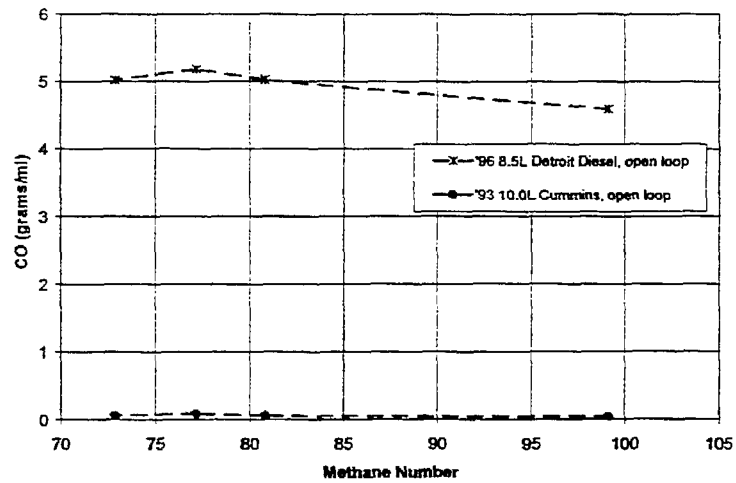
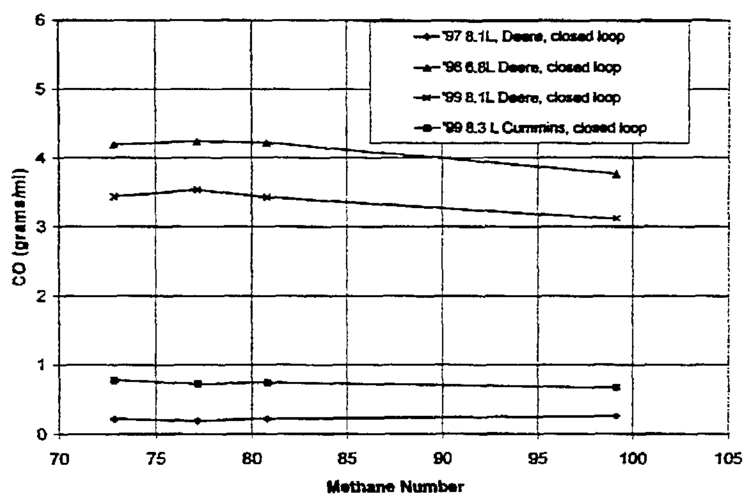


Figure B-17: CO Emissions for Closed Loop Technology Engines



CO_2 emissions for both open and closed loop technology engines are shown in Figure B-18 and Figure B-19 below. The CO_2 emissions for the open loop engines were higher than for the closed loop engines for all fuel qualities. The 1993 Cummins open loop vehicle had significant emissions variation with fuel quality. However the 1996 Detroit Diesel open loop vehicle and all the closed loop vehicles experienced only a six percent increase in emissions from the MN81 to the MN73 fuel quality.

Figure B-18: CO_2 Emissions for Open Loop Technology Engines

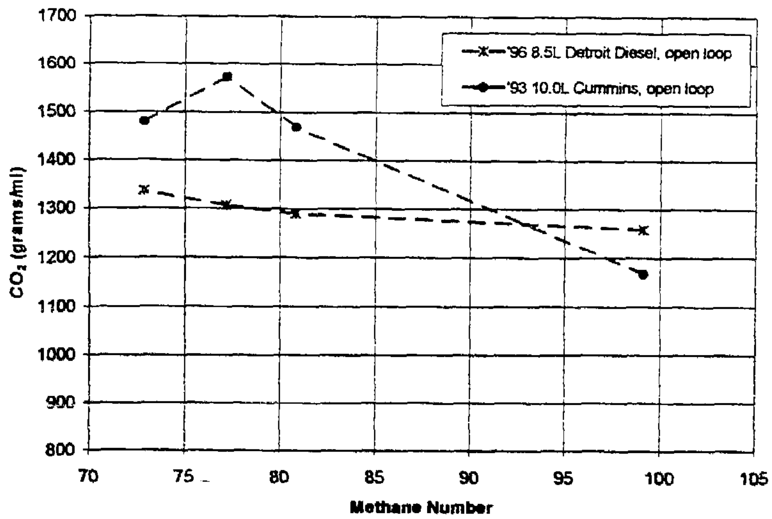


Figure B-19: CO_2 Emissions for Closed Loop Technology Engines

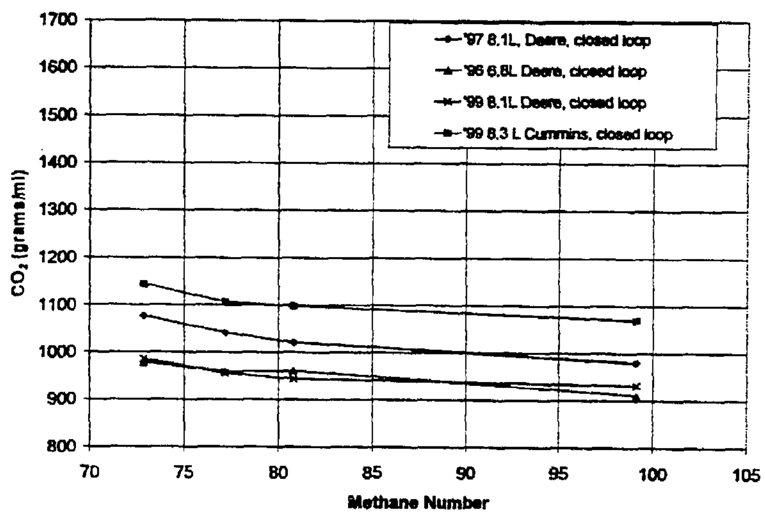


Figure B-20 and Figure B-21, below, show measured fuel economy as a function of fuel grade for the open and closed loop technology engines. The closed loop technology engines produced better fuel economy than the open loop technology-engines. All of the closed loop technology engines and one of the open loop technology engines obtained better fuel economy with the lower MN fuels than with the higher MN fuel. The lower MN fuels contain larger fractions of higher molecular weight hydrocarbons, resulting in a higher energy content. The closed loop technology engines were better able to utilize the higher energy content fuels by adjusting the air/fuel ratio accordingly. Consequently, the closed loop technology engines showed a more consistent increase in fuel economy with fuel variations, an average 20 percent increase from MN99 to MN73 fuel quality, than the open loop technology engines. The open loop technology Detroit Diesel engine also showed a 20 percent increase with decreasing fuel MN. However in contrast, the open loop technology Cummins engine showed a 9 percent decrease in fuel economy with decreasing fuel MN.

Figure B-20: Fuel Economy for Open Loop Technology Engines

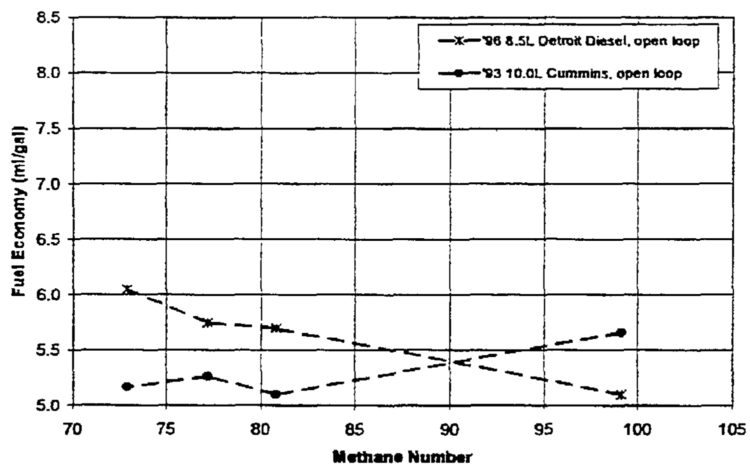
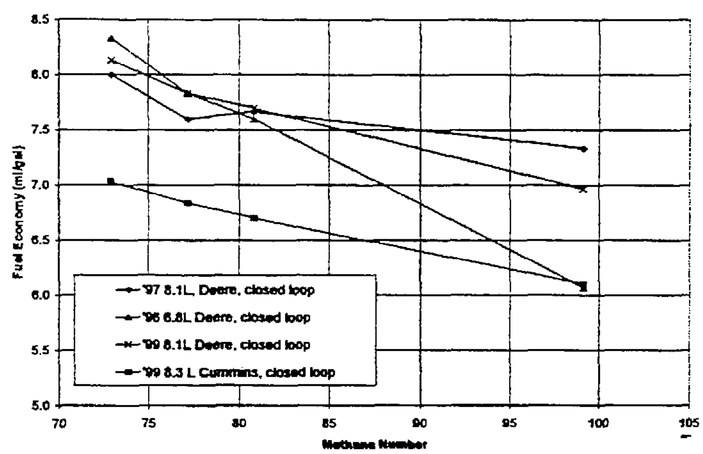


Figure B-21: Fuel Economy for Closed Loop Technology Engines



3. Data Analysis

a) Coefficient of Variance

The coefficient of variance (COV) for the data was maintained at less than 10 percent for the majority of the data, as summarized in Table B-8 for the three technology types.

Table B-8: Coefficient of Variance for Different Technology Groups

Technology Group	Average Coefficient of Variance (%)						
	THC	CO	NOx	CO_2	NMHC	Partic	Fuel Econ
Advanced Generation Closed Loop	2.8%	5.5%	3.5%	1.1%	3.3%	26.2%	3.7%
First Generation Closed Loop	2.6%	4.0%	2.7%	0.5%	3.0%	16.9%	0.6%
Open Loop	1.6%	15.2%	4.5%	0.9%	2.5%	43.1%	1.0%

The COV for the CO emissions exceeded 10 percent for three of the seven vehicles, the 1997 8.1L John Deere advanced generation closed loop technology school bus, the 1993 10.0L Cummins open loop technology transit bus, and the 1999/2000 12.7L Detroit Diesel Series 60G (LNG) closed loop technology tractor. The Detroit Diesel Series 60G (LNG) tractor was excluded from the summary due to inconsistent data trends. The high COVs for the John Deere and the Cummins vehicles were due to the low absolute value of the emissions. The standard deviations of the data were similar to that for the other test vehicles, but the measured CO emissions for these two vehicles were significantly lower, so the standard deviations were a higher percentage of the measured values.

The COVs for the PM emissions were also high due to low emission level. The COV for the PM emissions significantly exceeded 10 percent for at least two of the four fuels for every single vehicle, as evidenced in Table B-8. However, these high COVs were primarily due to the low measured PM emissions values. The PM test to test variations were small relative to more typical diesel PM measurements. However, again, these variations were a large percentage of the measured values for these vehicles. Consequently, while there appears to be a large degree of scatter in the PM emissions measurements, this variation is primarily due to the difficulty of measuring theses low values.

b) Statistical Analysis

A statistical analysis of the NOx and PM emissions data showed minimal statistically significant differences between the different vehicle technology groups and fuels for the UDDS cycle data shown in the preceding figures. The PM emissions data analysis indicated that only the first generation vehicle with the high quality fuel, which appears anomalously high, was statistically different, at a 95 percent confidence level, than any of the other vehicle/fuel combinations. The NOx emissions data analysis indicated that within individual vehicle technology groups, there were no statistically differences from fuel to fuel. However, the NOx emission response of the advanced generation closed loop technology engines showed less variation than either the first generation closed loop technology engine or the open loop technology engines, as shown in Figure B-22. The results of the statistical analysis are summarized in Table B-9 and Table B-10 for PM and NOx respectively.

Figure B-22: NOx Emission Response of the Different Engine Technologies

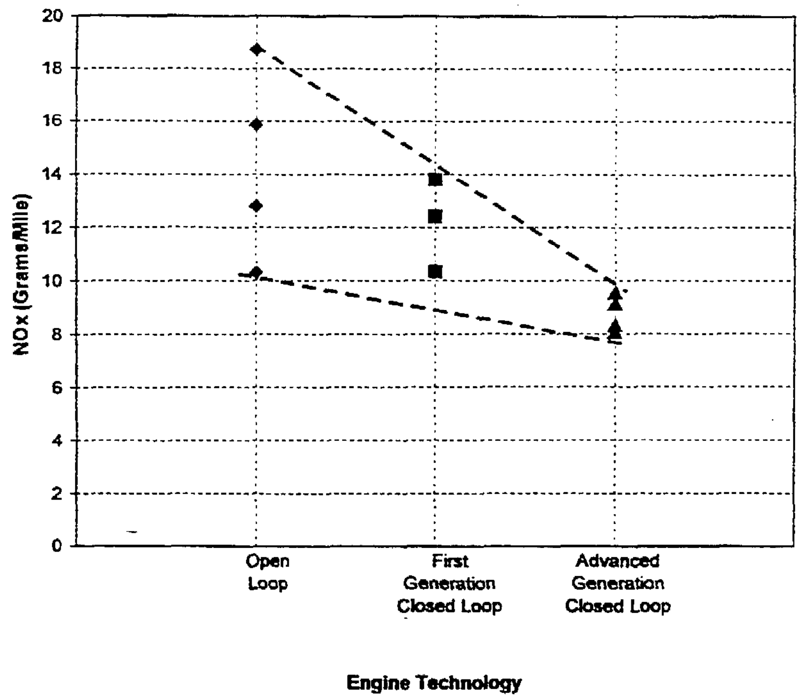


Table B-9: Statistical Mean and Standard Error of the PM Emissions for the Three Technology Groups and Four Fuel Qualities

UDDS Cycle					
Technology Group	Pollutant	Fuel MN	Mean	Standard Error	Group*
Closed Loop Advanced	PM	73	0.017	0.007	A
Closed Loop Advanced	PM	77	0.014	0.007	A
Closed Loop Advanced	PM	81	0.014	0.007	A
Closed Loop Advanced	PM	99	0.020	0.007	A
First Generation Closed Loop	PM	73	0.039	0.012	A
First Generation Closed Loop	PM	77	0.039	0.012	A
First Generation Closed Loop	PM	81	0.043	0.012	A
First Generation Closed Loop	PM	99	0.066	0.012	B
Open Loop	PM	73	0.039	0.009	A B
Open Loop	PM	77	0.035	0.009	A B
Open Loop	PM	81	0.042	0.009	A B
Open Loop	PM	99	0.029	0.009	A

* Means that share the same letter are not statistically different

Table B-10: Statistical Mean and Standard Error of the NOx Emissions for the Three Technology Groups and Four Fuel Qualities

UDDS Cycle Technology Group	Pollutant	Fuel MN	Mean	Standard Error	Group*
Closed Loop Advanced	NOx	73	8.1	2.6	C
Closed Loop Advanced	NOx	77	9.1	2.6	C
Closed Loop Advanced	NOx	81	9.6	2.6	C
Closed Loop Advanced	NOx	99	8.3	2.6	C
First Generation Closed Loop	NOx	73	12.4	4.6	C D
First Generation Closed Loop	NOx	77	13.8	4.6	C D
First Generation Closed Loop	NOx	81	12.4	4.6	C D
First Generation Closed Loop	NOx	99	10.3	4.6	C D
Open Loop	NOx	73	12.8	3.2	C D
Open Loop	NOx	77	15.9	3.2	C D
Open Loop	NOx	81	18.7	3.2	D
Open Loop	NOx	99	10.3	3.2	C D

*** Means that share the same letter are not statistically different**

D. Estimated Effect on Individual Vehicle Emissions

From the test data presented in the preceding sections, staff concluded that for the advanced generation closed loop technology engines the data show no discernable emissions impact for NOx, PM, THC and CO. However, the data indicate increases of approximately six and 10 percent in CO_2 and NMHC respectively from MN81 to MN73 CNG. For first generation closed loop technology the data show similar emissions trends. However, for open loop technology the data indicate significant increases in NMHC of up to approximately 50 percent.

Attachment B-1: Data Tables

Table A: Measured Emissions From Light-Duty Dedicated Fuel OEM Vehicles[1]

Vehicle Emissions (grams/mile) - Dedicated OEMs

NOx - FTP

Fuel	Wobbe	Accord	Crown Vic	Caravan	Ram Van	MN*
TF-1	1245	0.1175	0.0815	0.0988	0.2255	103
TF-2	1182	0.1045	0.0880	0.0850	0.1695	89
TF-3	1284	0.0930	0.0885	0.0630	0.2387	88
TF-4	1341	0.0963	0.1442	0.0930	0.1715	99
TF-5	1425	0.1050	0.0490	0.0980	0.2030	63

NOx - US06

Fuel	Wobbe	Accord	Crown Vic	Caravan	Ram Van	MN*
TF-1	1245	0.3840	0.3625	0.1645	0.2987	103
TF-2	1182	0.1570	0.2705	0.1340	0.2345	89
TF-3	1284	0.1865	0.1970	0.1040	0.2700	88
TF-4	1341	0.1203	0.3534	0.1680	0.2210	99
TF-5	1425	0.1360	0.0935	0.1503	0.2700	63

NMOG - FTP

Fuel	Wobbe	Accord	Crown Vic	Caravan	Ram Van	MN*
TF-1	1245	0.0146	0.0132	0.0076	0.0219	103
TF-2	1182	0.0159	0.0266	0.0219	0.0249	89
TF-3	1284	0.0181	0.0282	0.0194	0.0279	88
TF-4	1341	0.0119	0.0216	0.0175	0.0158	99
TF-5	1425	0.0239	0.0296	0.0123	0.0270	63

NMOG - US06

Fuel	Wobbe	Accord	Crown Vic	Caravan	Ram Van	MN*
TF-1	1245	0.0040	0.0038	0.0037	0.0040	103
TF-2	1182	0.0056	0.0049	0.0045	0.0021	89
TF-3	1284	0.0037	0.0042	0.0049	0.0044	88
TF-4	1341	0.0017	0.0055	0.0029	0.0035	99
TF-5	1425	0.0040	0.0041	0.0023	0.0046	63

CO - FTP

Fuel	Wobbe	Accord	Crown Vic	Caravan	Ram Van	MN*
TF-1	1245	0.5315	0.9525	0.2623	1.1925	103
TF-2	1182	0.7080	1.2640	0.4605	1.2365	89
TF-3	1284	0.7260	1.2615	0.3665	0.8283	88
TF-4	1341	0.7063	1.4974	0.2145	0.8590	99
TF-5	1425	0.6187	1.4815	0.2907	1.0870	63

CO - US06

Fuel	Wobbe	Accord	Crown Vic	Caravan	Ram Van	MN*
TF-1	1245	0.5970	1.1550	0.4813	1.6343	103
TF-2	1182	0.7545	1.4770	0.6545	1.2610	89
TF-3	1284	0.7010	1.3395	0.6110	0.9615	88
TF-4	1341	0.7527	1.8116	0.2435	1.0160	99
TF-5	1425.00	0.6760	1.6680	0.3423	1.1090	63

* ARB Staff Calculation

Table B: Measured Emissions From Light-Duty Bi-fuel and After-Market Conversion Vehicles[1]

Vehicie Emissions (grams/mile) - Bi-Fuel After Market Conversions and Prototype

NOx - FTP

Fuel	Wobbe	Dakota	Sierra	GMC Pas	QVM F250	MN*
TF-1	1245	0.0613	0.2893	0.3295	0.4890	103
TF-2	1182	0.0600	0.2650	0.4275	0.4820	89
TF-3	1284	0.0673	0.3910	0.3420	0.6170	88
TF-4	1341	0.0615	0.5070	0.3405	0.7075	99
TF-5	1425	0.0670	0.3015	0.3610	0.4765	63

NOx - US06

Fuel	Wobbe	Dakota	Sierra	GMC Pas	QVM F250	MN*
TF-1	1245	0.2280	0.4877	0.7375	0.6285	103
TF-2	1182	0.2940	0.4235	0.8120	0.6740	89
TF-3	1284	0.2935	0.5805	0.7325	0.7315	88
TF-4	1341	0.2370	0.7130	0.7700	0.7300	99
TF-5	1425	0.3170	0.5175	0.8080	0.5745	63

NMOG - FTP

Fuel	Wobbe	Dakota	Sierra	GMC Pas	QVM F250	MN*
TF-1	1245	0.0246	0.0327	0.0520	0.0452	103
TF-2	1182	0.0256	0.0550	0.0820	n/a	89
TF-3	1284	0.0616	0.0645	0.1179	0.1479	88
TF-4	1341	0.0245	n/a	0.0562	n/a	99
TF-5	1425	0.0334	0.0648	0.0946	0.1105	63

NMOG - US06

Fuel	Wobbe	Dakota	Sierra	GMC Pas	QVM F250	MN*
TF-1	1245	0.0023	0.0068	0.0262	0.0213	103
TF-2	1182	0.0033	0.0184	0.0717	n/a	89
TF-3	1284	0.0044	0.0135	0.0764	0.0488	88
TF-4	1341	0.0034	n/a	0.0427	n/a	99
TF-5	1425	0.0041	0.0154	0.0771	0.0418	63

CO - FTP

Fuel	Wobbe	Dakota	Sierra	GMC Pas	QVM F250	MN*
TF-1	1245	2.9727	3.1593	5.8705	3.5800	103
TF-2	1182	3.0585	3.9595	6.4060	2.4220	89
TF-3	1284	3.6863	3.6100	7.0400	3.3060	88
TF-4	1341	2.7850	3.6160	5.9830	2.9340	99
TF-5	1425	3.1605	3.8565	6.9345	3.2380	63

CO - US06

Fuel	Wobbe	Dakota	Sierra	GMC Pas	QVM F250	MN*
TF-1	1245	3.6005	3.4223	7.3355	4.7420	103
TF-2	1182	3.9195	4.6905	7.8355	3.6990	89
TF-3	1284	4.3705	4.1320	8.2180	4.4495	88
TF-4	1341	3.9160	3.9233	7.5235	4.3950	99
TF-5	1425	4.1515	4.2080	8.2880	4.5340	63

* ARB Staff Calculation

Table C: Light-Duty Dedicated OEM Vehicle Fuel Economy Data[1]

Dedicated NGVs (OEMs)
Average Fuel Economy (mpg)

Fuel	Wobbe	CH4/THC Vol. %	Lower Heating Value (LHV)	Specific Gravity X LHV	Accord	Caravan	MN*
TF-1	1245	0.981	864	512	27.69	21.15	103
TF-2	1182	0.938	839	519	31.66	20.67	89
TF-3	1284	0.910	913	566	36.62	22.68	88
TF-4	1341	0.967	922	536	34.22	23.38	99
TF-5	1425	0.848	1101	799	43.65	20.64	63

Fuel	Wobbe	CH4/THC Vol. %	Lower Heating Value (LHV)	Specific Gravity X LHV	Ram Van	Crown Vic	MN*
TF-1	1245	0.981	864	512	17.54	22.47	103
TF-2	1182	0.938	839	519	18.31	23.82	89
TF-3	1284	0.910	913	566	17.93	23.62	88
TF-4	1341	0.967	922	536	17.16	21.88	99
TF-5	1425	0.848	1101	799	22.08	28.97	63

* ARB Staff Calculation

Table D: Light-Duty Bifuel and After-Market Conversion Vehicles Fuel Economy Data[1]

Bi-Fuel After Market Conversion and Prototype
Average Fuel Economy (mpg)

Fuel I	Wobbe	CH4/THC Vol. %	Lower Heating Value (LHV)	Specific Gravity X LHV	QVM F250	GMC PAS	MN*
TF-1	1245	0.981	864	512	13.94	12.95	103
TF-2	1182	0.938	839	519	15.52	13.47	89
TF-3	1284	0.910	913	566	15.74	13.62	88
TF-4	1341	0.967	922	536	14.70	12.74	99
TF-5	1425	0.848	1101	799	18.65	15.97	63

* ARB Staff Calculation

Table E: Summarized HD Data for UDDS Cycle[2]

TEST CYCLE: UDDS

'97 8.1L, Deere, closed loop							
#1	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	7.97	0.26	7.62	980.1	0.43	0.016	7.33
80.8	7.47	0.22	8.98	1020.3	1.34	0.029	7.67
77.2	7.71	0.19	8.16	1040.7	1.41	0.006	7.60
72.9	7.52	0.22	7.10	1077.1	1.466	0.008	8.00

'99 8.3 L Cummins, closed loop							
#2	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	9.59	0.68	10.34	1069.9	1.90	0.07	6.10
80.8	7.18	0.75	12.40	1097.7	1.80	0.043	6.70
77.2	7.16	0.72	13.79	1106.2	1.78	0.039	6.83
72.9	7.33	0.78	12.42	1143.7	1.89	0.039	7.03

'96 6.8L Deere, closed loop							
#3	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	8.43	3.77	11.39	910.3	1.79	0.013	6.07
80.8	7.90	4.22	12.84	961.2	2.60	0.009	7.60
77.2	7.90	4.24	12.51	959.2	2.74	0.008	7.83
72.9	8.22	4.20	11.03	978.1	2.91	0.011	8.33

'99 8.1L Deere, closed loop							
#4	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	8.59	3.12	5.96	931.6	1.97	0.032	6.97
80.8	7.91	3.43	6.86	944.1	2.71	0.016	7.70
77.2	8.06	3.64	6.76	956.2	2.87	0.027	7.83
72.9	7.99	3.44	6.07	985.3	2.97	0.031	8.13

'96 8.5L Detroit Diesel, open loop							
#5	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	11.01	4.59	14.24	1258.9	2.42	0.02	5.10
80.8	9.07	5.01	20.76	1290.1	3.03	0.033	5.70
77.2	8.96	5.18	22.57	1306.7	3.14	0.031	5.75
72.9	12.79	5.02	7.52	1336.3	4.67	0.021	6.05

'93 10.0L Cummins, open loop							
#6	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	5.16	0.04	6.39	1167.1	0.96	0.03	5.66
80.8	5.25	0.06	16.66	1468.7	1.30	0.051	5.10
77.2	6.40	0.08	9.15	1573.2	1.65	0.041	5.27
72.9	5.22	0.06	18.04	1478.5	1.30	0.055	5.17

'99/'00 12.7L DD (LNG), closed loop							
#7	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	15.00	6.45	4.53	1101.1	0.85	0.52	8.80
80.8	13.53	10.88	6.10	1084.3	2.71	0.482	8.90
77.2	14.64	13.48	6.46	1083.8	3.24	0.512	8.83
72.9	14.19	7.53	4.47	1139.8	3.34	0.500	8.50

*ARB staff calculation

Table F: Summarized HD Data for Mod-CBD Cycle[2]

TEST CYCLE: MCBD

'97 8.1L, Deere, closed loop								
#1	Tailpipe Emissions (GRAMS/MI.)							Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic		(MI/Gal.)
99.1	5.06	0.16	3.88	767.1	0.329	0.008		9.43
80.8	4.64	0.14	4.56	788.2	0.78	n.a.		9.97
77.2	4.90	0.18	4.60	811.1	0.86	0.004		9.80
72.9	4.53	0.14	4.09	825.2	0.82	0.008		10.47

'99 8.3 L Cummins, closed loop								
#2	Tailpipe Emissions (GRAMS/MI.)							Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic		(MI/Gal.)
99.1	5.01	0.53	7.28	831.9	1.01	0.028		7.87
80.8	3.87	0.57	9.28	853.0	0.95	0.03		8.67
77.2	3.82	0.59	9.04	845.7	0.93	0.026		9.00
72.9	3.91	0.59	8.59	872.6	0.99	0.028		9.30

'96 6.8L Deere, closed loop								
#3	Tailpipe Emissions (GRAMS/MI.)							Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic		(MI/Gal.)
99.1	6.29	3.38	8.38	766.4	1.40	0.006		8.43
80.8	5.81	3.89	9.12	805.1	1.97	0.004		9.10
77.2	5.87	4.01	10.70	822.0	2.06	0.006		9.17
72.9	6.36	3.90	7.02	838.4	2.24	0.006		9.73

'99 8.1L Deere, closed loop								
#4	Tailpipe Emissions (GRAMS/MI.)							Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic		(MI/Gal.)
99.1	5.50	2.68	3.82	759.6	1.29	0.033		8.57
80.8	4.78	2.94	4.32	755.1	1.65	0.019		9.67
77.2	5.14	2.99	4.15	781.2	1.87	0.019		9.60
72.9	5.31	2.97	3.79	813.4	2.00	0.025		9.87

'96 8.5L Detroit Diesel, open loop								
#5	Tailpipe Emissions (GRAMS/MI.)							Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic		(MI/Gal.)
99.1	7.69	3.49	8.04	1013.5	1.68	0.025		6.40
80.8	6.70	3.78	11.15	1039.8	2.25	0.04		7.07
77.2	6.48	3.97	12.32	1039.1	2.25	0.022		7.23
72.9	8.43	3.91	4.44	1099.8	2.98	0.021		7.43

'93 10.0L Cummins, open loop								
#6	Tailpipe Emissions (GRAMS/MI.)							Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic		(MI/Gal.)
99.1	6.90	0.07	9.96	1454.0	1.26	0.090		4.50
80.8	4.14	0.04	9.70	1193.1	1.02	0.03		6.23
77.2	4.96	0.05	4.36	1242.0	1.30	0.030		6.67
72.9	3.87	0.06	11.24	1180.2	0.94	0.037		6.47

'99/'00 12.7L DD (LNG), closed loop								
#7	Tailpipe Emissions (GRAMS/MI.)							Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic		(MI/Gal.)
99.1	10.08	6.33	2.26	1051.7	0.82	0.175		9.33
80.8	8.50	7.43	2.95	1034.9	1.97	0.18		9.47
77.2	8.43	7.70	3.13	1050.6	2.14	0.177		9.33
72.9	10.35	6.19	2.20	1126.4	2.70	0.196		8.70

*ARB staff calculation

Table G: Summarized HD Data for Commuter Cycle[2]

TEST CYCLE: Commuter

'97 8.1L, Deere, closed loop							
#1	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	4.69	0.08	3.58	674.9	0.208	0.005	10.67
80.8	4.17	0.03	4.59	718.5	0.60	n.a.	10.97
77.2	3.97	0.08	4.33	690.1	0.62	0.007	11.57
72.9	3.77	0.04	4.47	711.3	0.57	0.009	12.13

'99 8.3 L Cummins, closed loop							
#2	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	4.69	0.30	3.99	723.8	0.96	0.075	9.07
80.8	3.47	0.34	5.46	712.4	0.81	0.02	10.33
77.2	3.58	0.35	5.05	715.7	0.83	0.035	10.63
72.9	3.53	0.34	4.92	737.4	0.85	0.031	10.97

'96 6.8L Deere, closed loop							
#3	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	4.66	2.64	10.22	627.1	0.99	0.009	10.30
80.8	4.35	2.90	11.63	662.0	1.46	0.006	11.10
77.2	4.52	3.01	11.49	676.9	1.58	0.021	11.13
72.9	4.47	2.93	9.80	681.7	1.55	0.004	12.00

'99 8.1L Deere, closed loop							
#4	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	4.55	1.95	4.40	614.2	0.99	0.033	10.60
80.8	5.08	2.40	4.56	714.3	1.74	0.030	10.20
77.2	5.14	2.45	4.32	717.4	1.83	0.027	10.47
72.9	5.17	2.45	4.20	740.8	1.92	0.013	10.83

'96 8.5L Detroit Diesel, open loop							
#5	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	5.27	3.05	7.81	894.7	1.24	0.020	7.27
80.8	4.32	3.43	10.65	926.4	1.43	0.03	8.00
77.2	4.02	3.53	11.91	914.5	1.39	0.018	8.27
72.9	5.95	3.45	4.20	983.9	2.19	0.024	8.37

'93 10.0L Cummins, open loop							
#6	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	4.08	0.04	8.32	1070.5	0.70	0.029	6.13
80.8	2.80	0.02	12.91	1075.0	0.61	0.02	6.97
77.2	2.44	0.02	16.34	1068.2	0.53	0.044	7.17
72.9	3.54	0.03	6.36	1137.5	0.82	0.020	7.30

'99/'00 12.7L DD (LNG), closed loop							
#7	Tailpipe Emissions (GRAMS/MI.)						Fuel Econ
MN*	THC	CO	NOx	CO2	NMHC	Partic	(MI/Gal.)
99.1	5.02	2.54	3.02	660.8	0.31	0.116	14.93
80.8	4.15	3.22	5.39	657.4	0.89	0.10	15.07
77.2	4.33	3.83	4.33	667.2	1.00	0.113	14.80
72.9	4.77	3.13	3.26	706.8	1.15	0.117	14.03

*ARB staff calculation

1 Bevilacqua, Oreste M., Ph.D. "Natural Gas Vehicle Technology and Fuel Performance Evaluation Program", Clean Air Vehicle Technology Center, File No. Z-19-2-013-96, April 1, 1997.

2 Bevilacqua, Oreste M., Ph.D., "Impacts of Natural Gas Fuel Composition on Tailpipe Emissions and Fuel Economy", ARB Public Workshop on the Alternative Fuels Regulations, Sacramento, CA, June 21, 2000.

3 Bevilacqua, Oreste M., "Natural Gas Vehicle Technology and Fuel Performance Evaluation Program (PEP), Phase II: Medium- and Heavy-Duty Vehicle Testing, Technical Proposal", Clean Air Vehicle Technology Center, December 18, 1998.

Appendix C - Overview and Results of LPG Testing Programs

A. LPG Emission Tests

Studies have been conducted to evaluate the impact of varying LPG quality on motor vehicle exhaust emissions. Three studies include the LPG Task Group test program, the WPGA test program, and the ARCO emission tests.

The LPG Task Group test program is the 1998 test program coordinated by staff with a LPG Task Group established by the ARB to oversee the project. The task group consists of representatives from refiners, engine makers, automakers, LPG marketers, and government agencies. The test program was initiated during the 1998 rulemaking to amend the motor vehicle LPG specifications. Emission tests were performed for both heavy duty and light duty vehicles on six different LPG fuel quality.

The WPGA study was sponsored by the WPGA in support of its 1996 petition to delay the 5 volume percent propene limit. Emission tests were performed on light duty duel fuel (LPG and gasoline) vehicles on indolene (Federal certification gasoline) and seven LPGs blends.

ARCO, with several co-investigators, conducted three emission tests on various propane/butane mixtures. Two of the tests, published in 1995, were laboratory studies on a light duty vehicle converted to LPG. The third study, published in 1998, was an in-use vehicle study (during the course of operation) on three medium-duty, LPG-converted transit vehicles.

1. Summary of Estimated Emission Effects of LPG Containing 10 Volume Percent Propene on Individual Vehicle

Table C-1 summarizes information from the three studies about the potential effects of propene and butane content on emissions. The LPG Task Group and the WPGA studies show that the 10 volume percent propene fuel resulted in a small increased (less than 10 percent) in NOx emissions in relation to the 5 volume percent propene fuel. The ARCO data indicate that for some LPG vehicles, emissions of hydrocarbons, CO, and OFP may increase slightly and NOx may decrease slightly at butane content of about 5 volume percent which is the current limit for butane. Detail discussion of the three studies are presented in the 1998 report, entitled, *Proposed Amendment to the Specifications for LPG used in Motor Vehicles*[1,2].

Table C-1: Estimates of Emission Effects in LPG Vehicles --

10% Propene and 5% Butane Fuel vs. 4% Propene and 2.0% Butane Fuel

(percent change)

Data Source	*NMHC or THC*	*NOx*	*CO*	*Ozone-Forming Potential*
Task Group HDV tests (Cummins Engine)	-18%	9%	6%	6%
Task Group LDV tests (Ford F-150)	-9%	-6%	1%	3%
WPGA LDV tests*	0	9%	2%	15%
ARCO LDV tests (butane effect, only)	small increase	small decrease	small increase	small increase
ARCO MDV tests (butane effect, only)	0	0	0	very small increase

* per ARB staff's regression analysis

2. Analysis of Emission Data from LPG containing Greater than 10 Volume Percent Propene on Heavy Duty Engine

Bobtails are LPG delivery trucks capable of fueling on the cargo fuel. Bobtails have been operating on commercial LPG. Commercial LPG fuel could contain from 15 to 30 volume percent propene in the summer months and could be as high as 60 volume percent propene during the winter months[3]. Of the three studies discussed above, only the Task Group study evaluated heavy duty engine on varying propene content as high as 21 percent. Thus, test data were re-evaluated to determine the emission effects of heavy-duty vehicle operating on LPG containing greater than 10 volume percent propene content.

Of the fuels selected by the Task Group, only two test fuels contain greater than 10 percent propene content. Table C-2 describes the two fuels and the base fuel which meets the current specifications of 10 volume percent propene or less and 5 volume percent butane or less. The fuels were tested in a Cummins B5.9 medium heavy-duty LPG engine

Table C-2: ARB/Task Group Test Fuels

Fuel	Propene, vol%	Butane, vol%*	Octane # **
Base	9.8	5.0	101.2
1	14.6	5.0	100.2
2	21.3	1.6	---

* Mean of all measurements
** (R+M)/2

The top half of Table C-3 shows, for the Cummins engine tests, the average emissions from the base fuel and from test fuels 1 and 2. The bottom half of the table shows the same results as percent changes relative to the base fuel average. Linear drift was seen for NOx emissions, therefore the adjusted NOx emissions are shown in the table. Emissions increased slightly for NOx from the beginning to the end of the test program. The emissions drift effect (as fit by a linear model) was statistically significant above a 90 percent confidence level but did not change the results significantly. The analysis and a graphical representation of the data for NOx is presented in the 1998 report.

Table C-3: Average Results for Cummins Engine

Fuel	Propene	Butane	NMHC	THC	CO	NOx*		NMOG	OFP
			Actual Emissions, grams/bhp-hr						
Base	9.8	5.0	.670	.702	.407	3.18	(3.19)	.689	1.14
1	14.6	5.0	.636	.670	.489	3.26	(3.24)	.849	1.34
2	21.3	1.6	.594	.623	.324	3.63	(3.56)	.518	1.07
			Changes Relative to 10% Propene Fuel						
1	14.6	5.0	-5%	-5%	**20%**	**3%**	**(2%)**	**23%**	**18%**
2	21.3	1.6	-11%	-11%	-20%	**14%**	**(12%)**	-25%	-6%

* Numbers in ( ) are adjusted for emissions drift effects.

As shown from the table, increasing the propene and butane contents of the LPG blends (fuel 1) appeared to decrease hydrocarbon emissions but increased oxides of nitrogen (NOx); non-methane organic gas (NMOG); and carbon monoxide (CO) emission, and the ozone-forming potential (OFP) of emissions. However, reducing the butane content to less than 2.5% (fuel 2), as specified in the commercial LPG standard, appeared to only increase NOx emissions. As seen from the table, the NOx emission increases could be as high as 14 percent more than a 10 volume percent propene fuel.

B. Performance and Durability Testing

The LPG Task Group test program also collects data regarding engine performance and engine durability associated with different formulations of LPG. Both tests were completed in 1999.

The LPG Task Group engine performance and combustion compared how a Cummins B5.9-195 LPG engine operates on a 10 volume percent propene fuel and on a 5 volume percent propene fuel for various internal temperatures, pressures, voltages, knock, and power. The objective of the tests was to determine if the engine continues to operate within the manufacturer's design limits while using the 10 volume percent propene fuel. The results reported was that in general, engine performance was unaffected by fuel blend. The engine was able to produce full power at each engine speed with both blends of fuel. No detonation was encountered (audibly or visually with an oscilloscope) with either fuel blend.

For the durability portion of the test program, 500-hour full-load dynamometer test was performed on the prototype Cummins B5.9L spark ignition propane engine on 10 volume percent propene fuel. Results show no abnormal wear to the engine.

Other reported performance testing was by Detroit Diesel. Detroit Diesel has reported testing LPG with 9.8 volume percent propene and 2.3 volume percent butane in a Detroit Diesel Series 50 engine for cold-start cranking and idle stability, peak torque and horsepower, and knock sensitivity. The test fuel was compared to a 5 volume percent propene fuel. Operation on the 9.8 volume percent propene fuel was indistinguishable from operation on the 5 volume percent propene fuel, except for greater knock sensitivity at 1500 revolution per minute (rpm) (but not other rpms). The knock sensitivity, measured as the maximum air-charge temperature that did not produce knock, was well within the design value and not expected to be encountered in normal use[1,2].

1 Air Resources Board, Proposed Amendment to the Specifications for LPG Used in Motor Vehicles, October 23, 1998.

2 Air Resources Board; "Motor Vehicle LPG Test Program (1997/1998)," http://www.arb.ca.gov/fuels/altfuels/lpg/mvlpge/mvlpge.htm.

3 Meetings and telephone contacts with individual California refiners, fall and winter 2000

Appendix D - Methane Number and Fuel Composition

Providing an optional methane number specification for the CNG motor vehicle fuel specifications satisfies both the need to control fuel variability according to the engine manufacturers requirements and to allow more flexibility in fuel composition. Several manufacturers of heavy-duty natural gas engines use either the methane number (MN) or motor octane number (MON) for specification of gas quality requirements.[1,2] Both the MON and the MN are measures of the knock resistance of the fuel with the difference being the reference fuels used.

A. Methane Number Correlation

The knock resistance of a fuel is determined by comparing the compression ratio at which the fuel knocks to a reference fuel blend that knocks at the same compression ratio. Different scales have been used to rate the knock resistance of CNG including the motor octane number (MON) and the methane number (MN). The differences in these ratings are the reference fuel blends used for comparison to the natural gas. The reference fuel blend used for comparison to the natural gas for the MON is composed of iso-octane, with an octane number of 100, and n-heptane with an octane number of 0. However, since natural gas has a higher knock resistance than iso-octane, tetraethyl lead (TEL) must be blended with the reference fuel to increase the reference MON.[3,4] The MON for CNG fuels range from approximately 115 to over 130. Methane number uses a reference fuel blend of methane, with a methane number of 100, and hydrogen, with a methane number of 0. The work documented in references 10 and 11 generated correlations between the reactive hydrogen/carbon ratio (H/C) and the MON and between MON and MN. The reactive hydrogen/carbon ratio, which excludes the carbon in the inerts, specifically the CO2, is the number of hydrogen atoms divided by the number of carbon atoms in the hydrocarbon components of the fuel. The correlations used by the engine manufacturers for MON as a function of H/C and MN as a function of MON are: [1,3,4]

$$MON = -406.14 + 508.04*(H/C) - 173.55*(H/C)^2 + 20.17*(H/C)^3$$
$$MN = 1.624*MON - 119.1$$

The correlation of MON with H/C ratio is shown in Figure D-1 below. The MON correlation is not valid for H/C ratios below 2.5 or for inert concentrations greater than 5%.

Figure D–1 Motor Octane Number as a Function of Reactive Hydrogen / Carbon Ratio

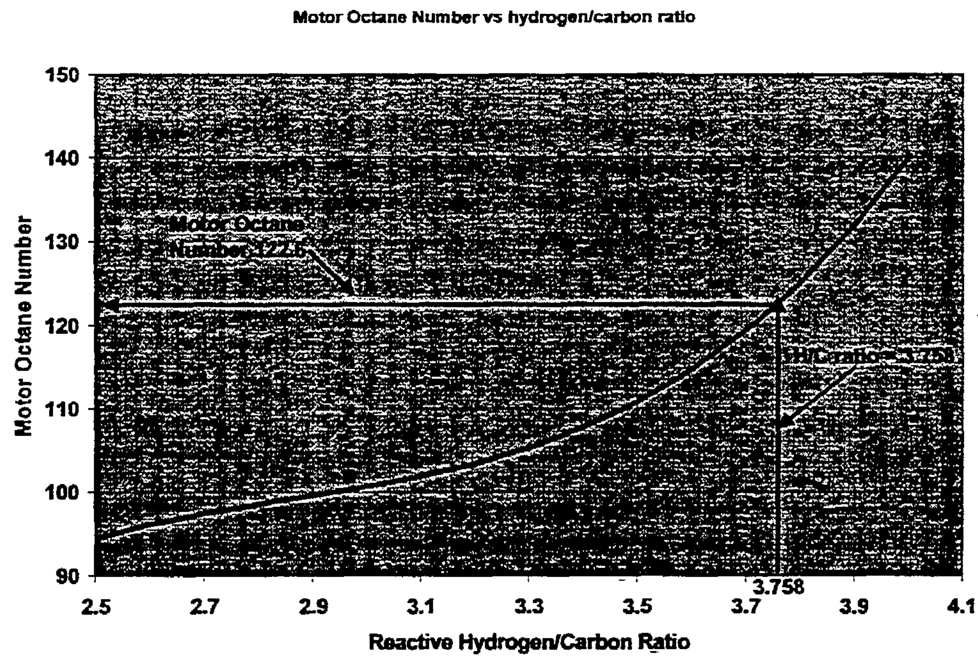
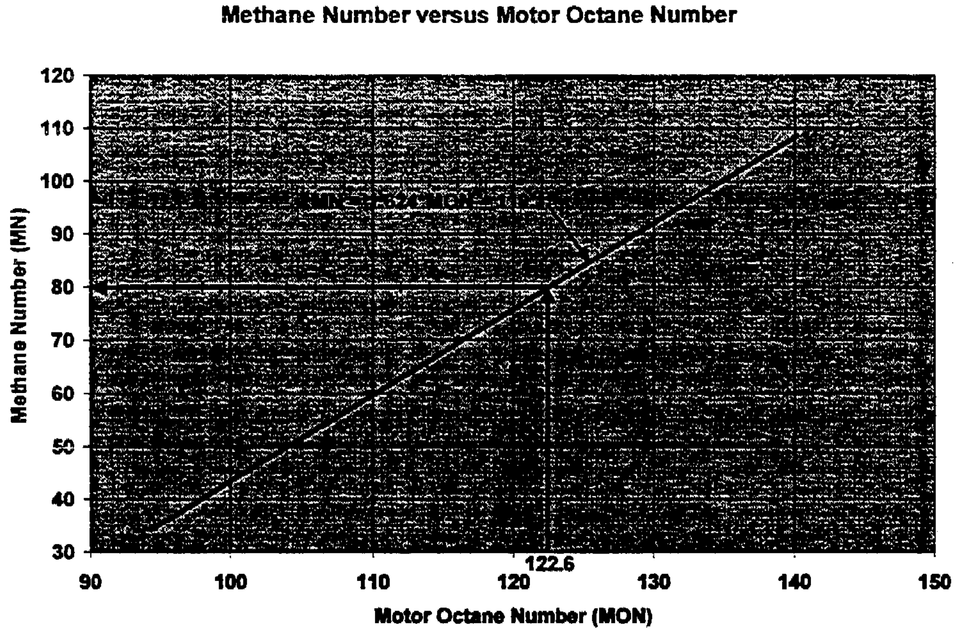


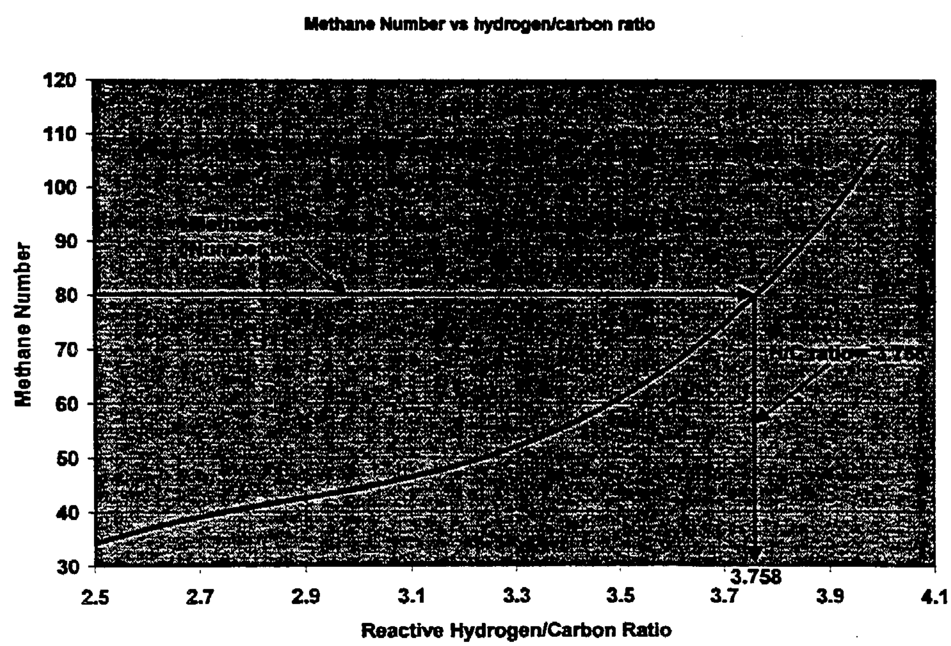
Figure D-2 below shows the relationship between MON and MN. From this figure it can be seen that a MON of approximately 122.6 is equivalent to a MN of 80. From Figure D–1 above, it is apparent that a reactive hydrogen/carbon ratio of 3.758 results in a MON of 122.6. Consequently, a reactive hydrogen/carbon ratio of 3.758 is necessary to obtain a MN of 80. This is shown in Figure D–3 below.

Figure D-2 Methane Number as a Function of Motor Octane Number



The MN can be shown as a function of reactive hydrogen/carbon ratio as shown in Figure D-3 below.

Figure D-3 Calculated Methane Number as a Function of Reactive Hydrogen/Carbon Ratio



B. Fuel Composition Flexibility

The proposed optional MN fuel quality specification being considered would allow gas compositions that do not meet the current compositional specification requirement to be compliant if the calculated methane number was at 80 or above. Thus, a gas specie could be higher than allowed by the current compositional specification if the overall reactive H/C ratio for the entire gas composition was a value of 3.758 or greater. For example, a gas with high ethane content could be compliant if the C3+ content was sufficiently low to compensate for it in the overall reactive H/C ratio.

Table D-1 gives an array of hypothetical gas compositions and the calculated methane number for each composition. The first two compositions do not meet the compositional CNG motor vehicle fuel specifications; however they would meet the proposed optional methane number 80 specification. The first gas, labeled low ethane, high C3+, has a C3+ content of 4.65%, which is over 50% higher than the current allowable level of 3%. However, the ethane content of 2.2% is much lower than the 6% allowable. The overall reactive H/C ratio is greater than 3.758, which gives a methane number of 80.4 for the composition. The second gas in the table, labeled high ethane, low C3+, has an ethane content of 8.66%, nearly 50% over the allowable 6%. However, the C3+ content of 1.86% is well below the allowable 3%, resulting in a reactive H/C ratio of just over 3.758 and a methane number of 80.

The last three hypothetical gases in Table D-1 meet the current compositional specification but have different C3+ compositions to illustrate the effect of heavier hydrocarbon components on methane number. All three gas compositions have 3% C3+. However the first of the three gases has C3+ that contains only propane whereas the other two gases have increasingly more of the heavy hydrocarbons in the C3+. The C3+ of the second of the three gases averages to a carbon atom number of 3.5 (C3.5) and that of the last gas averages to a carbon atom number of 4 (C4). The heavier hydrocarbons in the gas, which are those components with lower H/C ratios, lower the overall reactive H/C ratio of the gas and reduce the methane number, as shown in Figure D - 3 above. Consequently, the methane number for the three gases range from MN 82, for the gas with C3+ that is all propane (C3), down to MN 77, for the gas with the C3+ that averages to a C4.

The proposed methane number optional specification gives gas producers with non-compliant CNG motor vehicle fuel gas more flexibility in cleaning up their gas. Since heavier hydrocarbons condense at higher temperatures than the lighter hydrocarbons, they are easier to remove from the gas. This is evident from typical natural gas liquids (NGL) recovery efficiencies for different processes. Actual recovery efficiencies will vary with plant design and feed gas quality, however, a lean oil absorption plant can typically recover 99 percent of the butane and heavier hydrocarbons, 65 to 75 percent of the propane and 15 to 25 percent of the ethane from a natural gas. A typical refrigeration process can recover 100 percent of the butane and heavier hydrocarbons, 98 percent of the propane and 50 percent of the ethane. A typical cryogenic process can recover all of the propane and heavier hydrocarbons and 50 percent to over 90 percent of the ethane.[5]

Consequently, a gas producer with a high ethane content gas could chose to remove a portion of the heavier hydrocarbons to meet the proposed methane number 80 specification rather than reducing the ethane, which is more difficult to remove. Additionally, these heavier hydrocarbons are more marketable in California than ethane. One possible option is re-injection of these heavier components into the crude oil.

Table D-1 Example Gas Compositions Meeting Either the Proposed Methane Number 80 Specification or the Current Specifications

Mole Fraction:	Inerts	methane	ethane	C3+ total	C3+ constituents: propane	iso-butane	n-butane	iso-pentane	n-pentane	C6+	Reactive H/C	MON	MN
CNG meeting MN80:													
Low ethane, high C3+	0.0179	0.9137	0.022	0.0465	0.032	0.0031	0.0092	0.0008	0.0009	0.0005	3.763	122.9	80.4
High ethane, low C3+	0.046	0.8488	0.0866	0.0166	0.0142	0.0006	0.0014	0.0008	0.0012	0.0004	3.759	122.6	80.0
CNG meeting current specifications:													
Spec gas, C3+ all propane	0.03	0.88	0.06	0.03	0.03	0	0	0	0	0	3.780	123.9	82.1
Spec gas, C3+ averages to C 3.5	0.03	0.88	0.06	0.03	0.02	0.003	0.003	0.002	0.001	0.001	3.756	122.4	79.7
Spec gas, C3+ averages to C 4	0.03	0.88	0.06	0.03	0.01	0.0055	0.0055	0.0035	0.0035	0.002	3.731	121.0	77.4

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1 Facsimile from Vinod Duggal, Cummins Engine Co, to Lesley Crowell, ARB, dated February 26, 2001.

2 Paul Delong of John Deere, Telephone conversation with ARB Staff, 3/6/01.

3 Kubesh, John, King, Steven R., Liss, William E., "Effect of Gas Composition on Octane Number of Natural Gas Fuels", *Society of Automotive Engineers, Inc.*, SAE 922359, 1992.

4 Kubesh, John T., "Effect of Gas Composition on Octane Number of Natural Gas Fuels", SwRI-3178-4.4, GETA 92-01, GRI-92/0150, May 1992.

5 Spletter, Kathy, Adair, Lesa, "Processing", *Oil and Gas Journal*, May 21, 2001.

Appendix E – CNG Engine Performance

The variation in CNG composition seen throughout the South Central Coast and southern San Joaquin Valley can adversely affect engine performance. These effects can include misfire, stumble and underrated operation[1] as well as engine knock and overheating. These effects are dependent on the engine's ability to tolerate or compensate for the variation in fuel composition.

A. Stoichiometric Burn Engines

Engines designed for an air/fuel ratio that can completely burn the fuel without excess air remaining are called stoichiometric burn engines. Light-duty engines are stoichiometric burn engines. Stoichiometric burn engines have been used for light-duty application because they can be equipped with three-way catalyst exhaust after-treatment technology to meet light-duty vehicle exhaust emissions standards.[2] Additionally, the stoichiometric exhaust properties allow the use of a standard stoichiometric exhaust gas oxygen sensor for feedback control of the air/fuel ratio.[3] This feedback control improves engine performance with variable gas properties. However, these advantages come at a price of reduced fuel economy and higher combustion temperatures.

Stoichiometric light-duty engines are also more tolerant of variations in fuel composition. Stoichiometric conditions contain neither excess air nor excess fuel that would serve to dilute the combustion products and reduce combustion temperatures. Consequently, stoichiometric conditions are hotter or more severe than off-stoichiometric conditions and are more likely to cause knock, or detonation, than either richer (more fuel) or leaner (less fuel) conditions. Detonation occurs when there is uncontrolled combustion with multiple flame fronts rather than the combustion proceeding smoothly along a flame front from a single source of ignition, the spark plug.[4, 5] Detonation can be extremely damaging to hardware. Consequently, stoichiometric engines are designed to tolerate the most severe conditions, thus, changes in air/fuel ratio due to variable fuel quality moves the engine operation off stoichiometric to more benign conditions.[6]

B. Lean-Burn Engines

Engines designed to operate at an air/fuel ratio with more air than required to completely burn the fuel, referred to as excess air or lean fuel conditions, are called lean-burn engines. Medium and heavy-duty engines are usually designed as lean-burn engines because these engines are more fuel-efficient and produce lower combustion temperatures than stoichiometric burn combustion. This engine technology has been used to meet applicable exhaust emission standards without the use of after-treatment technology. Excess air both ensures that all the fuel is burned and dilutes the combustion products to reduce the combustion gas temperature. The lower combustion temperatures minimize NOx emissions without after-treatment as well as increase hardware life.

Lean-burn engines are more susceptible to problems arising from variable fuel quality. Most lean-burn heavy-duty engines are designed to operate close to the lean mis-fire zone to minimize

NOx emissions.[1] The lean mis-fire zone is the operating zone where there is too little fuel for the air provided to sustain the burning process. Changes in fuel quality for a lean burn engine can result in mis-fire if the change results in leaner conditions, or detonation and/or overheating if the change results in richer conditions.

C. Open Loop and Closed Loop Systems

All light duty stoichiometric burn engines include feedback controls that process information from the exhaust to aid in engine operation. This is called a closed loop system. Lean-burn engines can be designed either with or without feedback controls. Engines without feedback controls are called open loop systems. Open loop systems use a predetermined "map" of load and speed to determine the engine fuel injection requirements.[1] A certain fuel composition must be assumed to generate this "map". Consequently open loop systems are less tolerant of changes in fuel composition. Engines with closed loop systems have computers that use measurements of the oxygen content of the exhaust stream combined with information about the mode of operation (i.e. throttle level and fuel flow) to adjust engine operation for fuel quality.[1] The exhaust stream oxygen concentration allows the computer to determine how much excess air the engine is running. Light duty stoichiometric burn engines can use a standard stoichiometric exhaust gas oxygen sensor for the necessary feedback controls. However, lean burn heavy-duty engines require a special sensor, (such as a universal exhaust gas oxygen (UEGO) sensor) and/or a special computerized program for engine control.[3] Consequently, not all lean-burn closed loop systems provide the same degree of engine control. First generation systems are more susceptible to fuel quality related operational problems than more recent advanced generation systems. In general however, closed loop systems are more tolerant of changes in fuel composition.

Some higher compression ratio heavy-duty lean burn engines include an additional feedback for knock detection. Higher compression ratio makes an engine more susceptible to knock or detonation. If knock is detected via an accelerometer, the spark plug timing can be retarded, or caused to spark later in the cycle, to reduce knock.[5, 7] Retarding the timing, however, can reduce fuel economy.

D. Gas Quality Requirements

Two measures of CNG gas quality are the Wobbe Index and the methane number. The Wobbe Index is a measure of the fuel interchangeability with respect to its energy content and metered air/fuel ratio.[6, 8] Thus, changes in Wobbe Index can affect the engine's metered air/fuel ratio and power output.[9] The Wobbe Index is calculated from the energy content, or higher heating value of the gas, and the relative density of the gas. The relative density of the gas is the ratio of the gas density to the density of air.

Wobbe Index = Higher Heating value / (relative density)

The methane number is a measure of the knock resistance of the fuel. Knock, or detonation, can be extremely damaging to an engine. Knock occurs when there is uncontrolled combustion with multiple flame fronts rather than smooth combustion proceeding along a flame front initiated at the spark plug.[4,5]Knock can result from the heat produced by compression of the air/fuel gas mixture in the piston. The knock resistance of the fuel is a function of the fuel composition. Methane has a very high knock resistance. The heavier hydrocarbons in CNG, such as ethane, propane, and butane, have lower knock resistance and thus reduce the overall knock resistance of the fuel. Methane number and how it is determined in explained in Appendix D.

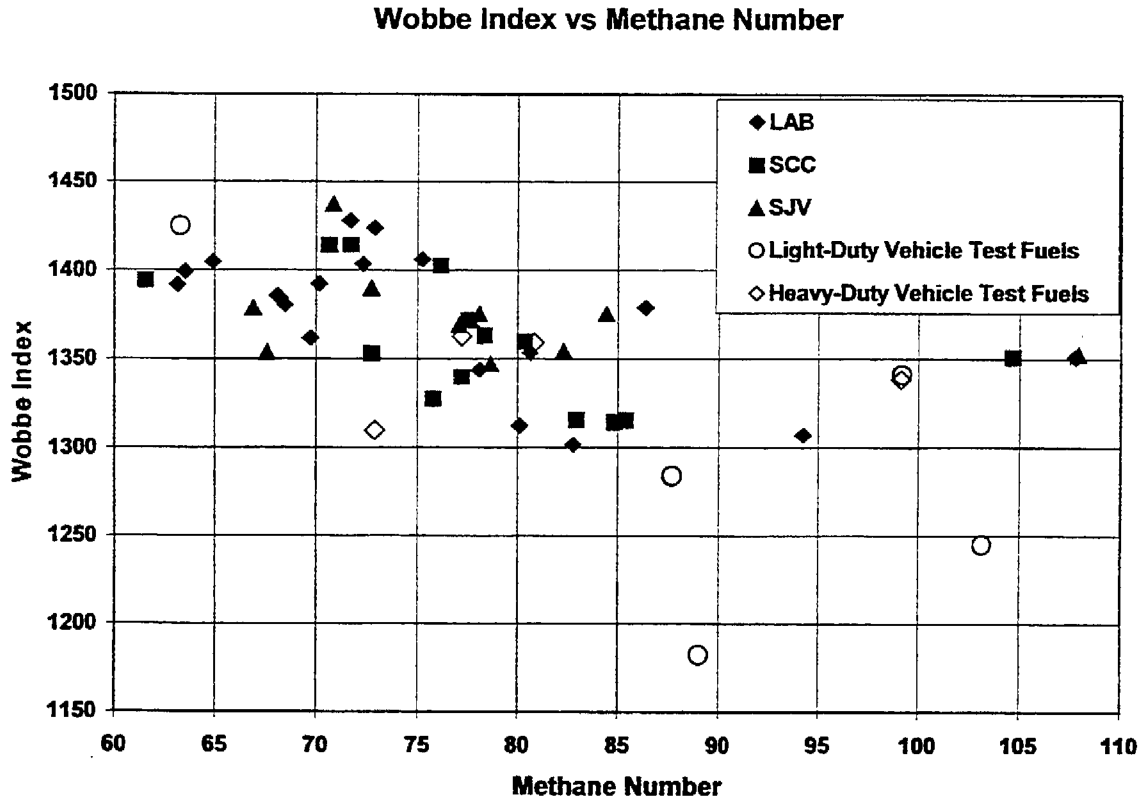
1. Light Duty Engines

Light duty natural gas engines run at stoichiometric burn conditions (sufficient air to completely burn the fuel without excess air remaining) and use closed loop control, making them extremely tolerant of the natural gas fuel variations seen in California. A survey of light duty vehicle manufacturers indicated that fuel quality requirements for light duty engines are more frequently cited in terms of Wobbe Index.

Wobbe Index values given as vehicle requirements range from approximately a minimum of 1300 BTU/ft3 to a maximum of 1400 to 1500 BTU/ft3.[10, 9] This requirement range encompasses the entire fuel quality range reported for the California South Central Coast (SCC), southern San Joaquin Valley (SJV), and the Los Angeles Basin (LAB) regions of approximately 1300 BTU/cu.ft. to 1450 BTU/cu.ft., as shown in Figure 1 below.[11] From this figure it can also be seen that this range encompasses methane numbers down to 65 to70.

Testing to determine the effect of fuel quality on emissions and driveability, discussed in Appendix B, was conducted using eight light-duty natural gas vehicles (NGV) with five different fuel qualities, ranging from a Wobbe Index of 1182 BTU/cu.ft. to 1425 BTU/cu.ft.[12] Staff calculated the methane number range for these fuels to be MN 65 to MN 100. The Wobbe Index and methane number for these test fuels are shown plotted in Figure E-1. Test results showed that for dedicated NGVs, even large variations in fuel composition produced only small variations in the emissions and driveabliltiy, while bifuel vehicles had only modest changes in emissions and performance.[12, 13]

Figure E-1: Wobbe Index and Methane Number Variations of California CNG Fuel [11, 12, 15]



2. Heavy Duty Engines

A survey of heavy duty vehicle manufacturers indicated that fuel quality requirements for heavy duty engines are more frequently cited in terms of methane number or motor octane number. Motor octane number and methane number are linearly related, as shown in Appendix D. A methane number of 80 is required for both open loop and first generation closed loop lean-burn heavy duty engines. However, more recent advanced generation closed loop lean-burn heavy-duty engines can tolerate a fuel quality down to a methane number of 73. Additionally, there are closed loop engines recently certified by ARB as a low emissions engine that can tolerate methane numbers as low as 65.[14]

Testing to determine the effect of fuel quality on emissions was conducted on seven heavy-duty vehicles using four fuels.[15] The results of this testing is summarized in Appendix B. The seven vehicles included five closed loop systems and two open loop systems. Three of the closed loop systems were recent advanced generation systems and the others were first generation systems. The results from one of the closed loop systems, an LNG vehicle, were excluded from the final data presentation due to problems with the vehicle operation. The four fuels tested included a high quality commercial grade fuel with a methane number of 99, a high ethane fuel with a methane number of 81, a high C3+ fuel with a methane number of 79, and a high inerts, ethane and C3+ fuel with at methane number of 73. Only the high quality commercial grade fuel complied with the current CNG motor vehicle fuel specifications. Based on staff calculations, the CNG certification fuel equates to a methane number of approximately 86 to 87 and the CNG in use fuel equates to a methane number of approximately 80 to 82. The high ethane fuel with a methane number of 81 is comparable in terms of methane number to the current minimum fuel quality specifications. Consequently, the emissions effects of allowing advanced generation closed loop systems to use fuel with a methane number of 73 can be evaluated based on a comparison to the methane number 81 fuel. There were increases in carbon dioxide (CO_2) and nonmethane hydrocarbon (NMHC) emissions of six percent and approximately 10 percent respectively. There were no discernable impacts on the other emissions.

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